GEOLOGY OF THE TONY BUTTE AREA AND VICINITY, MITCHELL QUADRANGLE, OREGON

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1953

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Date thesis is presented September 15, 1952

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ACKNOWLEDGMENTS

The writer wishes to thank Dr. W. D. Wilkinson, the major professor, and Dr. Lehi Hintze for their suggestions concerning field work and their assistance in editing the manuscript.

Sincere appreciation is extended to Dr. Ira S. Allison for his constructive criticism of the manuscript.

The work was greatly facilitated by discussions with Loren B. McIntyre and James Swarbrick, co-workers in the field and laboratory.

The writer is grateful to his wife, Helen E. Bowers, who helped in the preparation of the manuscript.

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INTRODUCTION

Location

The Mitchell quadrangle is located in Wheeler, Jefferson, Crook, and Wasco counties in north-central Oregon. The area considered in this paper, shown in Plate 1, is located in the southeastern part of the quadrangle between 44°36'31" and 44°40'00" north latitude, and between 120°00'00" and 120°17'08" west longitude.

Federal Highway 28 borders the area on the south. Secondary roads within the area include the Service Creek road, the road along Bridge Creek, and others in the vicinity of Tony Butte and the Painted Hills. Logging roads are numerous in the eastern sector but are in poor condition.

The town of Mitchell, with a population of about 200, is located about 3 miles south of the area. Fossil is 35 miles to the north; Dayville about 40 miles to the east; and Prineville about 51 miles to the southwest.

Size

The area forms a strip 4 miles wide and 14 miles long with the long dimension in an east-west direction. The total area is 56 square miles.

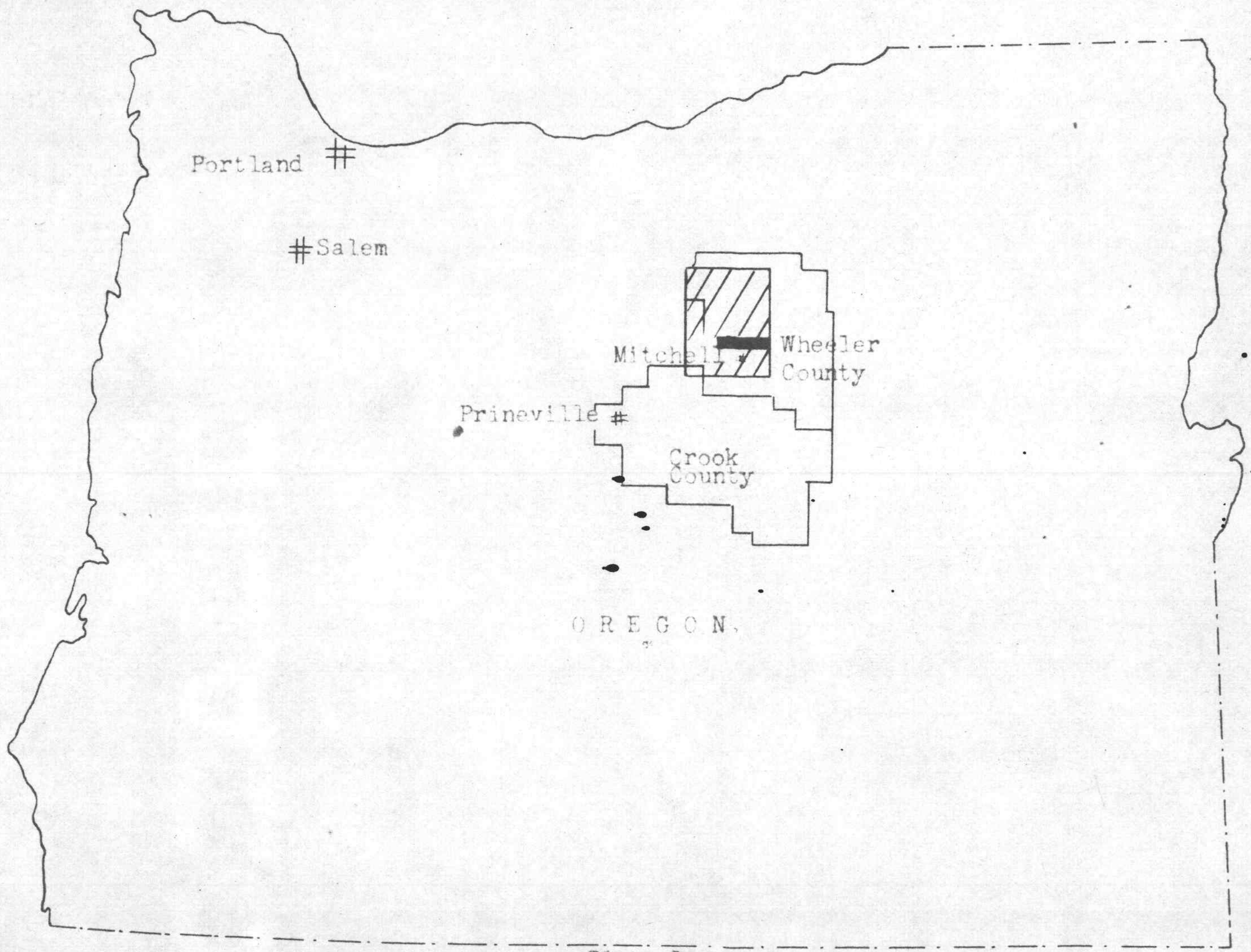


Plate 1.
Index Map Showing Location Of The Tony Butte Area, Oregon

Purpose of Investigation

The primary purpose was to map in as much detail as possible the areal geology of this area and thereby contribute to an understanding of the geology of the Mitchell quadrangle.

Methods of Investigation

The primary method of investigation was the actual field work which was undertaken in the summer of 1951, and during June, 1952. The time spent in the field was about 10 weeks.

As a supplement to the field work considerable laboratory work was done, including thin section studies and the preparation and identification of fossils.

Previous Work

Previous work in the area has been mostly of a reconnaissance nature and so the literature pertaining to it is limited.

In 1863, Thomas Condon, then a pastor at The Dalles, Oregon, collected fossil remains from the John Day formation along Bridge Creek and in 1870 sent some of these fossils to O. C. Marsh who later collected from the area. Condon's early interest was instrumental in bringing the area to the attention of later geologists. An excellent summary of early geological exploration in eastern Oregon is given by Merriam (19, p. 272).

In 1901, J. C. Merriam (19, p. 284) first described the Cretaceous rocks exposed in the vicinity of Mitchell, reporting these rocks to be 3000 to 4000 feet, of sandstone, shale, and conglomerate. He mentioned the anticlinal structure of these rocks along Bridge Creek and remarked upon the resemblance of the lower shales found at Mitchell to the Knoxville of California, and noted the similarity of the overlying conglomerate to the conglomerate at Spanish Gulch. Merriam thought that the east limb of the structure at Mitchell might represent the west limb of a syncline whose other limb was located at Spanish Gulch. He also states: "The relations of the Clarno to the Cretaceous may be seen just east of the town of Mitchell, where a considerable thickness of andesites and tuffs is resting upon the Chico."

Calkins, in 1903 (2, p. 122), described some andesites which overlie the Cretaceous sediments near Mitchell, and some Eocene volcanic rocks from Cherry Creek and from Clarno Ferry.

In 1914, A. J. Collier (7, p. 39-41), following Merriam, noted the occurrence of Cretaceous rocks near Mitchell and described the limestone exposed on Shoofly Creek. He considered it to be "Probably Carboniferous" in age.

In 1929, Packard (22, p. 166) wrote:

> "The largest area (of Cretaceous) lies within the Mitchell quadrangle and has been mapped by J. P. Buwalda. The Mitchell anticline has yielded a large and varied ammonite fauna, one horizon being traceable for nearly the length of the structure....Although final correlations have not yet been made, a part at least of the lower shales of the Mitchell anticline will probably prove to be of Horsetown age, while the coarser deposits higher in the section are undoubtedly of Chico age."

Hodge (12) in 1932, published a reconnaissance geological map of north-central Oregon which includes the area considered in this report.

In 1933, Chaney (3, p. 5) reported that a flora made up of cycads, found on a hill above Mitchell, had been referred provisionally by him to the Upper Cretaceous.

Moore (20, p. 148) in 1937, reported upon the limestone along Shoofly Creek.

In 1940, Packard (23, p. 295) divided the rocks of Cretaceous age exposed near Mitchell into four lithologic units and described marine invertebrate fossils collected from the Cretaceous rocks of the Mitchell anticline, concluding: "The lower shale fauna is most nearly allied to the middle and upper Horsetown of California."

From this brief resume' of previous geological work in the Mitchell area, it is evident that the emphacis has been upon the pre-Tertiary rocks exposed on the Mitchell anticline.

GEOGRAPHY

Topographic Relief

The maximum topographic relief in the area is about 3320 feet. A minimum elevation of about 1880 feet occurs along Bridge Creek while the maximum elevation of about 5200 feet occurs in the southeastern part of the area.

Climate

The climate at Mitchell is similar to that at Dayville where precise data have been collected for 52 years. At Dayville, and presumably at Mitchell, the annual average temperature is 50.5° and the average annual precipitation is 11.53 inches (30, p. 310, 312). In general, the summers are hot, and most of the precipitation occurs during the winter months.

Vegetation

Vegetation over most of the area consists of sagebrush, grasses, and occasional juniper trees. Along streams and around springs, cottonwood and willow grow, while on the high ridges in the southeast there are forests of ponderosa pine.

Drainage

The principal stream is Bridge Creek which flows northwest through the western part of the area. With its tributaries it drains the southwestern, northwestern, and the central sectors. East of Sutton Mountain, and north and southeast of B.M. 3599, as shown on the topographic map, the drainage is north through Girds Creek and Shoofly Creek. Bridge Creek, Girds Creek, and Shoofly Creek join the John Day River in the central portion of the quadrangle. Other streams to which reference will be made are Meyers Creek, Rattlesnake Creek, and Limekiln Creek.

GENERAL GEOLOGY

General Features

The oldest rocks exposed are metamorphosed marine sediments, probably of Paleozoic age, which occur on the flanks of Tony Butte and at Meyers Canyon. Locally these rocks contain ultramafic dikes and greenstone of pre-Tertiary age. The Mitchell beds of Cretaceous age, consisting of shale, sandstone, and conglomerate, overlie the meta-sediments unconformably and are exposed on both limbs of the Mitchell anticline.

Tertiary rocks exposed are dominantly of volcanic origin and include the Clarno, John Day, and Columbia River Basalt formations. Intrusive rocks of Tertiary age consist of basalt, andesite, and dacite, in the form of plugs, dikes, and sill-like bodies.

The principal structural feature is the Mitchell anticline which trends northeasterly through the area. Strike faulting on the northwest limb and intrusions along the axis have complicated and obscured the anticlinal nature of this fold.

The exposed rock units and their relationships are shown in Table 1, and the areal geology is shown on the geologic map, Plate 2.

Pre-Tertiary Sedimentary Rocks

1. General Statement

Pre-Tertiary sedimentary rocks occur along the axis and on the limbs of the Mitchell anticline. Two pre-Tertiary units are recognized: the Tony Butte meta-sediments, and the overlying Mitchell beds.

2. Tony Butte Meta-sediments

Name. The basement rocks in this area have not yet been given a published formational name. In this paper they will be referred to as the Tony Butte meta-sediments.

Table 1

Summary of Rock Units in the Tony Butte Area and Vicinity, Mitchell Quadrangle, Oregon

Age	Rock Unit	Character	Thickness (in feet)
Quaternary		Alluvial gravel, sand, ash and silt	0-70
Middle Miocene	Columbia River Basalt fm.	Olivine basalt flows, olivine basalt dikes	1200
	unconformity		
Lower Miocene	Upper and Middle John Day fm.	Buff and green tuffs, welded tuff layer	3100
Upper Oligocene	Lower John Day fm.	Red and buff tuffs	
	unconformity		
Eocene (?)	Intrusives	Dacitic, andesitic and basaltic plugs, dikes and sill-like bodies.	
Eocene	Clarno fm.	Mudflows; volcanic breccias; basaltic, andesitic, dacitic flows and associated tuffs	1000-3200
	unconformity		
Upper Cretaceous	Frizzell conglomerate unit	Marine conglomerate, sandstone and shale	3168
Lower Cretaceous	Frizzell shale unit	Marine shale and sandstone	2200
Lower Cretaceous	Basal Mitchell unit	Marine sandstone and conglomerate	189-1300
	unconformity		
Pre-Cretaceous	Intrusives	Ultramafic rocks and greenstone	
	relations unknown		
Paleozoic Upper (?)	Tony Butte meta-sediments	Metamorphosed marine sediments	950-4700 (?)

Distribution and Topographic Expression. Outcrops occur on the flanks of Tony Butte; at the head of Meyers Canyon; along Limekiln Creek south of Rattlesnake Creek; in the east central part of Sec. 33, T. 10 S., R. 22 E, and in the SW.$\frac{1}{4}$ Sec. 12, T. 11 S., R. 22 E. The total areal extent is about 2 square miles.

Meta-sediments form resistant ridges on the southern, southwestern and eastern flanks of Tony Butte, and continue eastward into the Limekiln Creek Valley. The length of this belt is nearly 3 miles, its width from about 0.2 to 1.3 miles. On the eastern flank of Tony Butte these rocks are largely inferred from fragments in the soil and from one small outcrop at an elevation of 4000 feet.

Similar rocks occur at the head of Meyers Canyon and form a northeasterly trending ridge (Fig. 1) which continues to the southwest beyond the area. The rocks strike northeast, are vertical or dip steeply to the southeast, and are exposed in a belt about 0.8 mile long.

At Meyers Canyon the strike of the meta-sediments conforms to the trend of the ridge, but at Tony Butte and in Limekiln Creek many of the ridges are transverse to the general strike.

Lithology. This unit consists of marine sediments. Folding, fracturing, and low grade regional metamorphism have obscured many of the original sedimentary structures.

Rock types include phyllite, quartzite, chert, limestone and crystalline limestone, calcareous sandstone, grit, and pebble conglomerate. Phyllite, quartzite, and chert are the most abundant rocks.

(1) Phyllite. Phyllite occurs as narrow elongate outcrops (Fig. 2), 5 to 10 feet high and 20 to 200 feet long.

The surface of the outcrop often has a blocky or hackly appearance. A fresh surface has a distinct sheen and shows various shades of grayish black, greenish gray, or greenish blue, while the weathered surface is dark brown or greenish gray.

The phyllite is foliated parallel to the general strike of the outcrop and is easily spalled off in large flat slabs parallel to this foliation. It is much crumpled and fractured and at places shows small drag folds.

(2) Quartzite. Quartzite forms resistant outcrops (Fig. 3) and where in contact with phyllite shows slightly more relief than the latter. On the outcrop it is dark gray, brown, or light red, and on the fresh fracture is light red, light blue, gray, or white. It is characterized by small, irregular, closely spaced intersecting fractures which cause the rock to break into rectangular blocks. Locally the surface has a schistose appearance caused by thin layers of greenish chloritic material.

Under the microscope the rock has a fine-to medium-grained mosaic texture. Quartz grains and an occasional grain of plagioclase feldspar are the main constituents (Fig. 4). The quartz grains show a tendency towards elongation. Small veinlets of secondary quartz fill and heal the fractures which are so evident in the hand specimen.

(3) Chert. Outcrops of chert are usually massive in appearance and are partly brecciated and healed by silica and iron oxide.

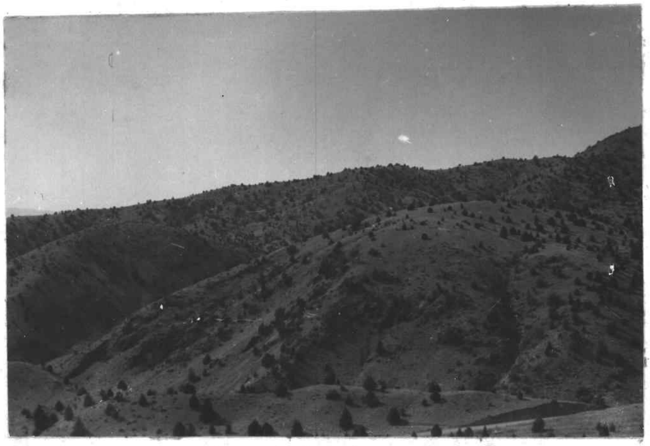


Figure 1. Exposure of metasediments on north side of Meyers Canyon. A dacitic plug forms the ridge on left edge of photograph.

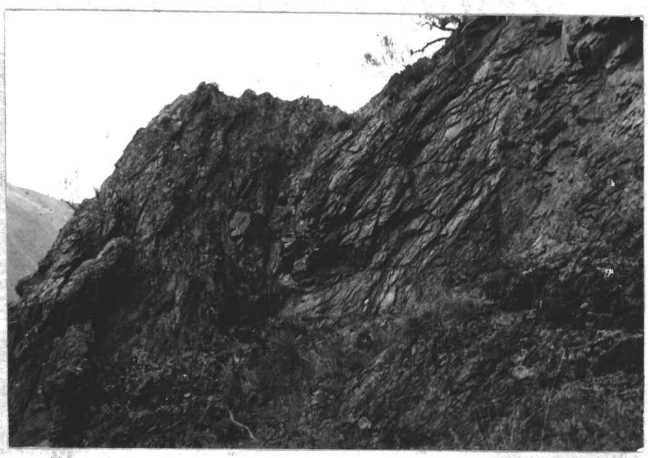


Figure 2. Outcrop of phyllite about 10 feet in height exposed at the head of Meyers Canyon.

Figure 3. Exposure of quartzite on the southern flank of Tony Butte.

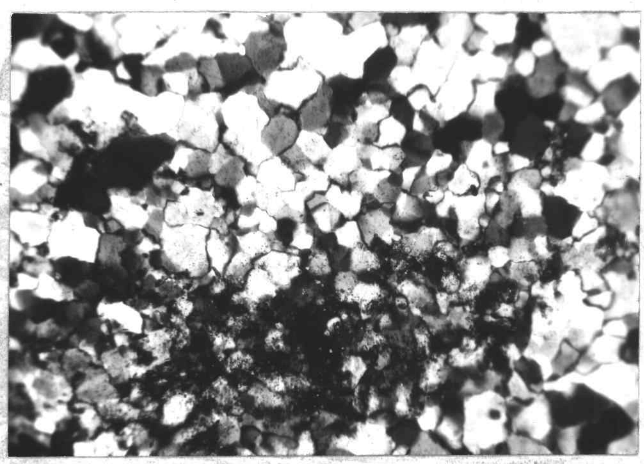


Figure 4. Photomicrograph of quartzite from the Tony Butte metasediments. Crossed nicols, x90.

The outcrop is grayish black to light brown, while the fresh surface is dark gray, light gray or light red. The rock is tough and breaks with a splintery fracture.

Microscopically the rock shows a cryptocrystalline texture crossed by numerous small fractures which have been filled with vein quartz. In some specimens an unidentified, black amorphous substance is present in small, roughly parallel wisps. Limonite and stringers of dark green chlorite extend through the rock and show a rough alignment.

(4) Limestone. The limestone varies in appearance from a massive to a schistose rock. Outcrops are 2 to 20 feet wide and as much as 300 feet long and stand in relief above the other rocks in the unit. Beds are usually vertical or nearly so (Fig. 5) and give an indication of the attitude of the unit as a whole. The weathered surface is rough because of small projections of chert which stand above the surface as much as $\frac{1}{4}$ inch. On the outcrop the limestone is blue-gray, while on the fresh fracture it has a mottled appearance, with adjacent areas of light gray and blue gray.

Under the microscope the limestone shows some crushing and recrystallization. Chert was present in three slides examined and averaged about 4%. Chemical analysis was not undertaken, but judging from the color of the weathered surface the magnesium content is probably low.

(5) Calcareous sandstone, grit, and pebble conglomerate. These rocks appear in a valley on the southwest flank of Tony Butte where

they appear to be interbedded with quartzite and phyllite. The best exposure occurs on the western side of the valley in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 3, T. 11 S., R. 22 E., at an elevation of about 4000 feet. The outcrop varies in exposed thickness from about 70 feet at the north end of the exposure to less than 5 feet at the south end. It may be traced for a distance of about 300 feet. Scattered outcrops also occur on the eastern side of the valley.

When first examined these rocks were thought to overlie the meta-sediments and to form a distinct unit between the meta-sediments and the overlying Mitchell Beds. Later examination revealed that they appear to be interbedded with the older rocks, although it is difficult to reconcile the relatively unaltered appearance of some of the sandstone with the metamorphic aspect of other rocks in the meta-sediments.

The rocks are well indurated marine fossiliferous sandstones and grits with small lenses of intercalcated pebble conglomerate. They are dark greenish gray (5GY 4/1) on the fresh surface (21), and range from grayish brown (5Y 3/2) to moderate brown (5Y 3/4) on the weathered surface. Differential weathering causes resistant fragments of quartz and chert to stand in relief above the other constituents.

Microscopically the sandstone and grit show angular to subrounded rock and mineral fragments firmly imbedded in a partially recrystallized calcite matrix. The composition and estimated percentages of the constituents are as follows:

Constituent	Per cent	Constituent	Per cent
Quartz and chert	30	Titanite	T
Calcite	30		
Feldspar	3	Meta-sediments and meta-volcanics (undifferentiated)	25
Magnetite	T		
Biotite	T	Quartzite	7

The greenish color of the rocks is caused by fragments of meta-sedimentary and meta-volcanic rocks which are greenish to dark gray. Many of the fragments show crushing and some are bent. Narrow veinlets of calcite cut both matrix and fragments. The source rock from which the sediments were derived evidently had been fractured and veined as shown by quartz and serpentine veinlets restricted to the rock fragments.

This rock is rather unusual in that the mineral and rock fragments "float" in a calcareous matrix (Fig. 6). As the fragments are usually not in contact with one another the origin of the rock is a problem.

Pettijohn (24, p. 483) describes sandstones somewhat similar to these and states:

> "Anderson interprets such rocks as an original mixture of clastic quartz and clastic carbonate. Clastic carbonate readily dissolves and reprecipitates and loses thereby all traces of its clastic origin. Such rocks grade into limestones with a few 'wind blown' quartz grains....Although in some sandstones such floated grains are an illusion, in others little doubt remains that the grains are in truth wholly separated from one another."

The origin of the calcareous sediments at Tony Butte is not known, but they may have originated in the way Pettijohn describes. Another explanation is that the fragments were washed into, and

Figure 5. Vertical bed of limestone about 8 feet in thickness exposed on the western edge of the Limekiln Creek Valley.

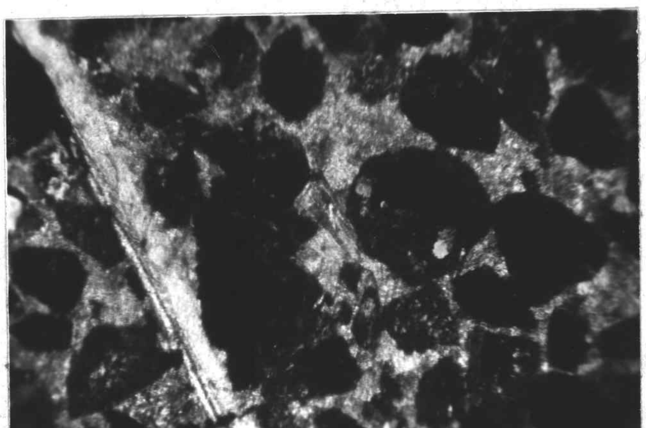


Figure 6. Photomicrograph of calcareous sandstone from the Tony Butte metasediments. Note the "floated" appearance of the rock and mineral fragments in the calcareous matrix. Crossed nicols, x90.

imbedded in a limy mud which upon consolidation formed the calcareous rocks.

Thickness. The exposed thickness of the meta-sediments could not be determined with certainty because the beds are generally vertical or have high dips and so may be repeated by isoclinal folding.

The apparent thickness exposed at Meyers Canyon as scaled from the geologic map is about 950 feet, while south of Tony Butte the apparent thickness varies from 2300 feet south of the butte to 4700 feet on the western edge of Limekiln Creek.

Paleontology. Fossiliferous limestone occurs in the SW. 1/4, NE. 1/4, Sec. 1, T. 11 S., R. 22 E., and this location is marked on the geologic map as O. S. C. fossil locality 4103. Here an outcrop of limestone 4 feet wide and about 200 feet long appears to strike southeast and is interbedded with chert. It contains silicified crinoid stems and fragments of brachiopod shells (Fig. 7). Mr. G. Arthur Cooper of the Smithsonian Institution (35), identified the fossils shown in Fig. 7 as "fillings of the cavity that runs the length of a crinoid stem." These are the first fossils reported from the pre-Cretaceous limestone of the Mitchell area. A list of the faunule is as follows:

Crinoid stems
Brachiopod fragments

On the southwest flank of Tony Butte in the NE. 1/4, NE. 1/4, Sec. 3, T. 11 S., R. 22 E., at an elevation of about 4000 feet, marine invertebrate fossils are present in the calcareous sandstone and

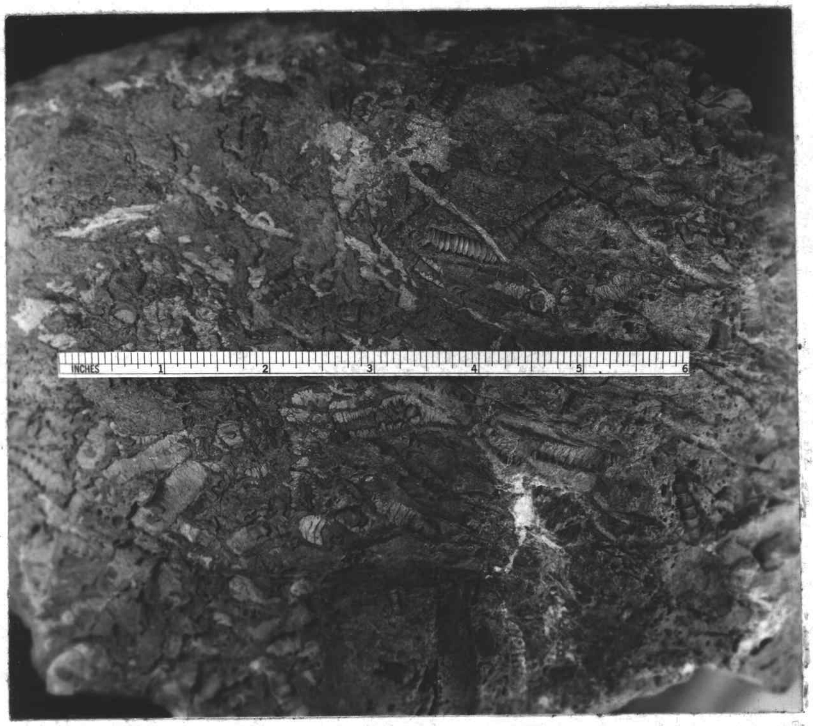


Figure 7. Fossiliferous limestone from locality 4103.
Fossils are silicified crinoid stems.

grit. The locality is marked on the geologic map as 4100. The fossils are rather poorly preserved but some shell material is present. The known faunule consists of a clam, snails, brachiopods, and foraminifera (Fig. 8). No specific identifications were made but a list of the faunule is given below:

Fusuline foraminifera
<u>Rhynchonella</u> sp. A
<u>Rhynchonella</u> sp. B
<u>Rhynchonella</u> sp. C
Gastropods
Clam

<u>Origin and Conditions of Deposition.</u> The presence of marine invertebrate fossils in the unit indicates that the rocks accumulated in the sea. The original deposits consisted of mud, sand, gravel, colloidal silica, and chemical or organic limy precipitates which upon consolidation formed shale, sandstone, conglomerate, chert, and limestone. Subsequent folding and low grade regional metamorphism converted the shale to phyllite; the sandstone, in part, to quartzite; and the limestone, in part, to crystalline limestone.

The nature and extent of the basin of accumulation are not known, but the apparent thickness suggests that they may have accumulated in a geosyncline.

<u>Relations and Age.</u> The Tony Butte meta-sediments are the basement rocks in the area and are overlain unconformably by the basal unit of the Mitchell beds at Meyers Canyon and in the vicinity of Tony Butte. They are also in contact with younger dacitic intrusive rocks at both localities. They are overlain unconformably by the

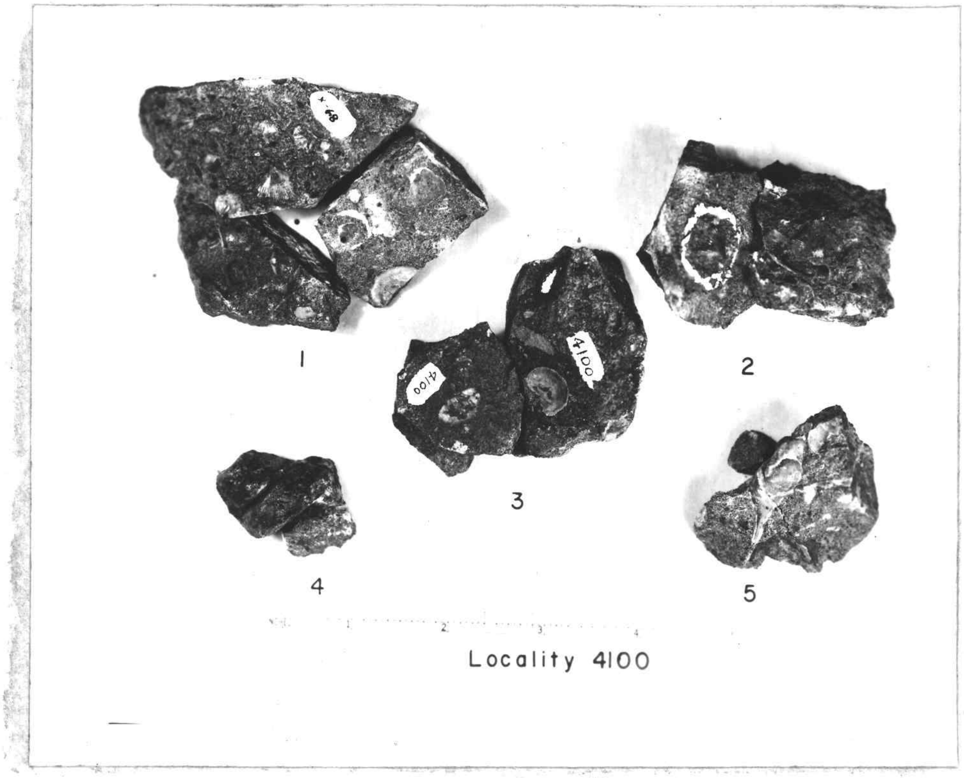


Figure 8. Fossils from locality 4100.

1 Rhynchonella sp. A
2 Rhynchonella sp. B
3 Rhynchonella sp. C
4 Gastropod
5 Gastropod

Clarno formation and in places are in fault contact with this formation.

Fossils discovered in the unit suggest that the age is Paleozoic, probably Pennsylvanian or Permian. A precise dating of the beds will depend upon more extensive collections and specific identifications of better preserved fossil material.

Similar rocks have been described by Coleman (6, p. 20) and by Dobell (10, p. 20) from the Picture Gorge and Dayville quadrangles. They apparently are not fossiliferous and have not been specifically dated.

Dawson (18, p. 10) has reported phyllite, quartzite, and limestone from the Birch Creek area of the Dayville quadrangle, which he considers on fossil evidence to be Permo-Triassic in age.

THE MITCHELL BEDS

General Statement

The marine sedimentary beds of Cretaceous age exposed in the area have not yet been given group or formational designation, but in this paper are referred to as the Mitchell beds, within which three lithologic units have been recognized and mapped. Names given to these units are not proposed as formational or member names, but are used merely to facilitate the presentation of data.

The oldest unit recognized consists of fossiliferous marine sandstone and pebble conglomerate which rests with angular unconformity upon metamorphic rocks at Meyers Canyon and upon similar rocks in the vicinity of Tony Butte. These rocks will be referred to as the Basal Mitchell unit.

Marine fossiliferous shale with interbedded sandstone conformably overlies this Basal unit and will be referred to as the Frizzell shale unit.

Overlying the Frizzell shale conformably are graywacke pebble conglomerates with interbedded graywacke sandstone and shale, which as a whole will be called the Frizzell conglomerate unit.

Marine invertebrate fossils occur within each of these units and descriptions of the faunules appear in the sections concerned with paleontology.

A. Basal Mitchell Unit

Distribution and Topographic Expression. This unit is exposed at Meyers Canyon, on the flanks of Tony Butte, and along Limekiln Creek. At Meyers Canyon it forms a narrow belt about 300 feet wide and 3600 feet long along the eastern margin of the meta-sediments (Fig. 9). It also occurs as a small patch on the southwestern margin of the meta-sediments.

Similar rocks occur in a semi-peripheral arrangement on the south, southwest, and eastern flanks of Tony Butte. From the eastern margin of the butte they continue to the east and are exposed almost as far as Limekiln Creek. Another small exposure occurs on the nose of a ridge along Limekiln Creek in the SE. $\frac{1}{4}$ Sec. 1, T. 11 S., R. 22 E.

The rocks do not stand out topographically in contact with the meta-sediments, but they are more resistant than the overlying Frizzell shale and do stand in relief above this unit.

Lithology. The unit is composed of medium-to coarse-grained sandstone and pebble conglomerate. At Meyers Canyon, sandstone and five interbedded conglomerate layers are exposed. Near Tony Butte thin-bedded sandstone with occasional shale partings is overlain by pebble conglomerate beds which in turn are overlain by medium-bedded sandstone. East of Tony Butte the rocks are poorly exposed but appear to be pebble conglomerate.

(1) Sandstone. The sandstone is fine-to medium-grained marine fossiliferous sandstone; it is well bedded, with individual beds ranging in thickness from several inches to four feet. On the outcrop the color varies from moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2) and yellowish gray (5Y 7/2). Color banding is common with alternating bands of various shades of brown extending into the rock for a distance of several inches. Quartz and rock fragments are discernible with the hand lens.

Two specimens from Meyers Canyon were examined microscopically. They are poorly sorted and composed chiefly of angular fragments of quartz, chert, feldspar, and rock fragments, cemented by silica and iron oxide (Fig. 10). A sandstone near the top of the unit has the following estimated composition:

Figure 9. Beds of sandstone and conglomerate of the Basal Mitchell unit overlying metasediments at the head of Meyers Canyon. Basal beds dip about 20° to the southeast.

Figure 10. Photomicrograph of sandstone from the Basal unit at Meyers Canyon. Note the angularity of quartz and rock fragments. Crossed nicols, x20.

Constituent	Per cent	Constituent	Per cent
Quartz	35	Pyrite	T
Chert	20	Sericite	T
Orthoclase	10	Kaolinite	T
Plagioclase	5	Epidote	T
Limonite	4	Meta-sedimentary and meta-igneous rock fragments undifferentiated	26
Biotite	T		
Magnetite	T		

(2) Pebble conglomerate. The pebble conglomerate is composed of rounded to sub-rounded pebbles and an occasional cobble set in a matrix of angular, medium-to coarse-grained sandstone. Individual beds range in thickness from 3 to 12 feet (Fig. 11). On the outcrop the conglomerate varies in color from grayish brown (5YR 3/2) to dark yellowish brown (10YR 4/2). The pebbles have an average diameter of about 1.5 inches, although cobbles 6 inches in diameter are locally present.

No pebble count was made at Meyers Canyon, but the conglomerate beds in the upper portion of the section appear to contain more dark-colored pebbles than those lower in the section. Near Tony Butte a count of 100 pebbles from a restricted area showed the following percentages of rock types:

Rock type	Per cent	Rock type	Per cent
Quartzite and chert	50	Meta-sedimentary (undifferentiated)	12
Meta-igneous (undifferentiated)	26	Felsitic igneous rocks	7
		Granitic rocks	5

Thickness. A section of this unit was measured at Meyers Canyon by Hintze (35) and several students during the 1951 field season. A total exposed thickness of 189 feet was recorded. On the southern flank of Tony Butte no precise data on the thickness of the unit were obtained, but as scaled from the geologic map the maximum thickness exposed there appears to be about 1300 feet.

Measured Section. A section of this unit was measured by several students under the direction of Dr. Hintze in 1951. It begins on the north side of Meyers Canyon in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 13, T. 11 S., R. 21 E., at the contact of the meta-sediments and the lowermost conglomerate bed of the Basal unit. From this point the section runs southeast to the contact with the overlying Frizzell shale. A generalized compilation of the field notes of the section is as follows:

Field description	Thickness (in feet)	Cumulative Thickness (in feet)
Fine- to medium-grained yellowish brown sandstone. No fossils noted	60	189
Pebble conglomerate showing a vertical gradation in size from 1-2 inches at the base to $\frac{1}{4}$ inch near the top	5	129
Fine- to medium-grained, yellow to brown sandstone containing grains of hornblende	5	124
Pebble conglomerate. The contact with the underlying sandstone is somewhat wavy	3	119
Fine- to medium-grained, pale yellowish brown sandstone. Poorly preserved marine invertebrate fossils. Fossils are mostly small clams and are abundant in two zonules 66 and 74 feet above the base of the section	73	116

Field description	Thickness (in feet)	Cumulative thickness (in feet)
Pebble conglomerate. Lowest 1 foot of bed contains some cobbles. Questionable plant remains	3	43
Fine-grained, angular sandstone, pale yellow to brown of the fresh surface. Plant remains are present	10	40
Conglomerate. Sub-rounded pebbles with some cobbles near the base. Quartzite and chert pebbles are dominant. Outcrop is iron-stained	4	30
Medium-grained sandstone, angular grains, yellowish brown on the weathered surface. Plant remains are common. The contact with the overlying conglomerate is wavy	5	26
Poorly exposed outcrop, covered with sand and loose pebbles. Probably sandstone	16	21
Conglomerate. Rounded to sub-rounded pebbles with an occasional cobble. The pebbles are chiefly light-colored quartzites and cherts with lesser amounts of dark colored meta-sedimentary and meta-volcanic rocks	5	5

Paleontology. The sandstone contains poorly preserved marine invertebrate fossils and considerable fossil wood (Fig. 12). The invertebrate material includes small clams and some small snails. Only casts of these fossils were found and no identifications were made.

Origin and Conditions of Deposition. The occurrence of a marine invertebrate faunule within the unit indicates that the sediments were deposited in the sea. The angularity of the sandstone constituents and the poor sorting of the sandstone suggest a relatively near-by source.

Figure 11. Pebble conglomerate bed in the Basal Mitchell unit exposed on the southwest flank of Tony Butte. Note presence of some cobbles.

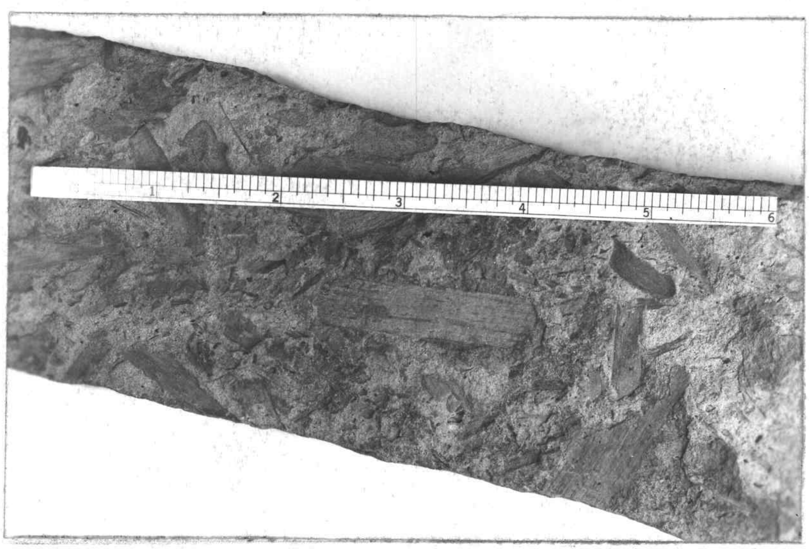


Figure 12. Slab of sandstone from the Basal Mitchell unit containing unidentified fossil wood.

A notable feature of the unit is the alternation of the sandstone and conglomerate which may be explained by periodic uplifts of the source area.

Conglomerate pebbles are generally rounded, suggesting either that the pebbles were rounded in transit to the site of deposition or that they represent reworked pebbles derived from Paleozoic or earlier Mesozoic conglomerates.

Consideration of the above factors suggests that the unit was deposited under marine near-shore conditions, as the initial phase of a marine transgression over a pre-Cretaceous erosion surface. The source area probably was relatively near, and consisted of rocks similar to the metamorphics now exposed at Meyers Canyon and near Tony Butte.

Relations and Age. The unit rests with angular unconformity upon the Tony Butte meta-sediments. At Meyers Canyon this relationship is well exposed where the meta-sediments and the Basal unit both strike generally to the northeast and both dip to the east and southeast. The discordance in dip between the two units is from 55° to 60°, as the Basal unit dips 20° to 30° and the meta-sediments dip from 70° to 90°. The sandstone and conglomerate abut the older rocks at a sharp contact exposed at several localities.

Near Tony Butte the contact between the Basal unit and the meta-sediments is exposed only on the southwest flank of the butte near the mouth of a small valley where the meta-sediments appear to strike N. 60° E. and dip steeply to the southeast, while the overlying sandstone and conglomerate strike N. 60° W. and dip about 35° to the southwest.

At Meyers Canyon and at Tony Butte the Basal unit is overlain conformably by the Frizzell shale unit. On the western flank of Tony Butte the unit is inferred to be in fault contact with conglomerates which appear to be equivalent to the lower portion of the Frizzell conglomerate unit. It is also in fault contact with the Clarno formation along Limekiln Creek.

As none of the fossils which occur within the unit is specifically identified, the exact age of the unit is not known. Stratigraphically, it lies between the meta-sediments and the Frizzell shale unit, and is probably lower Cretaceous in age.

B. Frizzell Shale Unit

Distribution and Topographic Expression. This unit occurs along the central portion of the Mitchell anticline, entering the area in the vicinity of Meyers Canyon in the south central sector, and extending to the southern and western flanks of Tony Butte. In this area the unit has an areal extent of about 6.5 square miles.

Topographically the shale and sandstone form valleys and subdued ridges. The shales are poorly exposed over much of the area, as shale areas are generally cultivated. The limits of these cultivated areas give a rough approximation to the contact between the shale and the overlying conglomerate.

Lithology. The unit consists of marine shale with interbedded sandstone. Near the base, shale with occasional thin beds of sandstone is the usual lithology. Near the middle of the unit, sandstone becomes more common and forms beds 1 to 2 feet thick (Fig. 13), and as the top of the unit is approached the sandstone becomes dominant, with individual beds 1 to 4 feet thick separated by thin partings of shale.

(1) Shale. The shales are thinly bedded, well indurated, and locally crumpled and fractured. Individual beds range in thickness from a fraction of an inch to 3 inches. The material shows rather poor fissility, and in the strict sense might be classified better as mudstone. On the outcrop the shale is light olive gray (5Y 5/2) to olive gray (5Y 3/2), while on the fresh fracture it is grayish olive (10Y 4/2).

It is composed of clay and silt size particles of angular mineral fragments. Under the microscope, silt size particles of quartz and plagioclase feldspar are discernible. Pyrite fragments are rather common and sand size particles of quartz are sometimes seen. The mineralogy, color, and association with graywacke sandstones correspond to "chloritic shale" as defined by Krumbein and Sloss (16, p. 136).

Concretions as much as 8 inches in diameter are present in the shale. Near the base of the unit at Meyers Canyon, rounded or oval calcareous concretions, light brown in color and varying in diameter from 1 to 6 inches, are abundant. Many of them contain small amounts of pyrite or marcasite.

Exceptional septarian nodules are present. They are generally large oval-shaped nodules, 8 to 12 inches in diameter, which are calcareous in composition, and crossed by a network of intersecting cracks filled by calcite (Fig. 14).

Near intrusive contacts the shales are baked, hardened, and blackened for a short distance from the intrusive rock.

(2) Sandstone. The sandstones are thin- to thick-bedded graywacke or sub-graywacke sandstones. They are generally interbedded with shale but near the top of the unit they become dominant and beds as much as 4 feet thick occur. On the weathered surface the rock shows various shades of light brown or gray, while on the fresh fracture it is yellowish gray (5Y 7/2) to light olive gray (5Y 5/2).

Under the microscope the rock is seen to consist of fragments of quartz, chert, plagioclase feldspar, and rock fragments firmly cemented by a "paste" of clay and chlorite (Fig. 15). Secondary carbonate appears to have replaced part of the original matrix. A sample near the top of the unit has the following estimated composition:

Constituent	Per cent	Constituent	Per cent
Quartz and chert	50	Intergranular detritus (clay and chlorite)......	12
Plagioclase	10	Meta-sedimentary and meta-volcanic rock fragments	14
Orthoclase	2	Quartzite	3
Biotite	1		
Carbonate	8		

Thickness. A section of this unit was paced by the author in

Figure 13. Alternating beds of sandstone and shale in the Frizzell shale unit. Sandstone bed in foreground is about 1 foot in thickness.

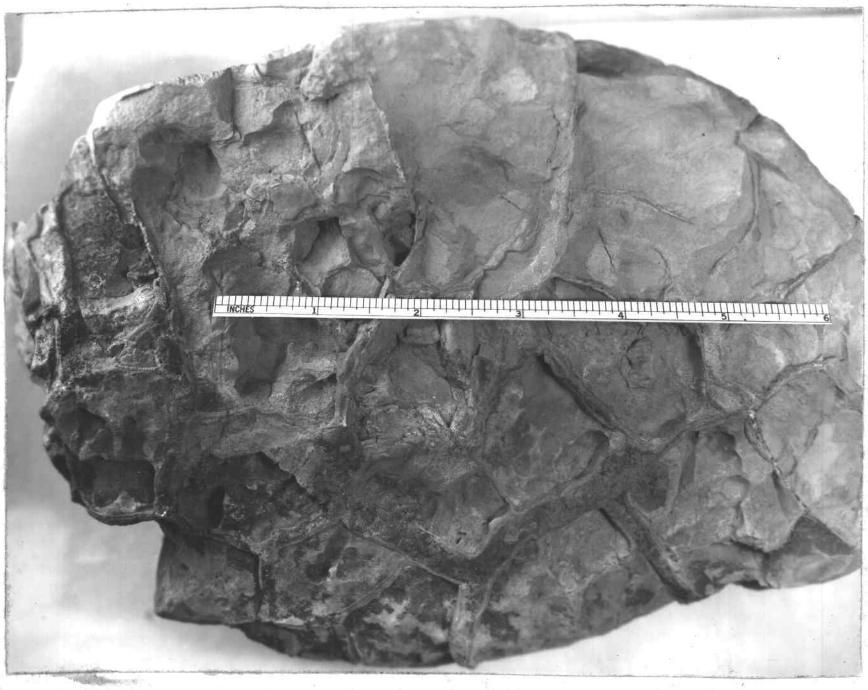


Figure 14. Septarian nodule from the Frizzell shale unit.

the area southeast of the Old Frizzell Ranch. The measurement started at the contact with the overlying Frizzell conglomerate and continued northwest to the assumed anticlinal axis. An exposed thickness of 2200 feet was measured. A section of this shale farther south was measured in the 1951 field season by students from the Oregon State College Field Camp. They recorded a total thickness of 2650 feet, beginning at the contact of the Basal unit at Meyers Canyon and proceeding southeast to the conglomerate contact. Packard (23, p. 295) reported 1800 feet of this shale along Bridge Creek below the town of Mitchell.

Paleontology. The unit contains marine invertebrate fossils including clams, snails, cephalopods, echinoids, brachiopods, and foraminifera. Fossils usually occur in concretions, although foraminifera have been reported by Heacock (35) from a silty layer within the shale.

Fossils were collected on the southwest flank of Tony Butte from the Frizzell shale immediately below the contact with the Frizzell conglomerate. The O. S. C. fossil locality number is 4102 and is plotted on the geologic map. At this locality the known faunule consists of ammonites and a small clam. The ammonites (Fig. 16) were identified as Sonneratia sp. by direct comparison with similar material collected and identified by Packard. Similar ammonites occur at Meyers Canyon about 150 feet above the contact of the shale with the Basal Mitchell unit.

Fragments of the ammonite Desmoceras sp. were observed near

Figure 15. Photomicrograph of graywacke sandstone from the Frizzell shale unit. Note angularity of quartz, feldspar and rock fragments. Crossed nicols, x25.

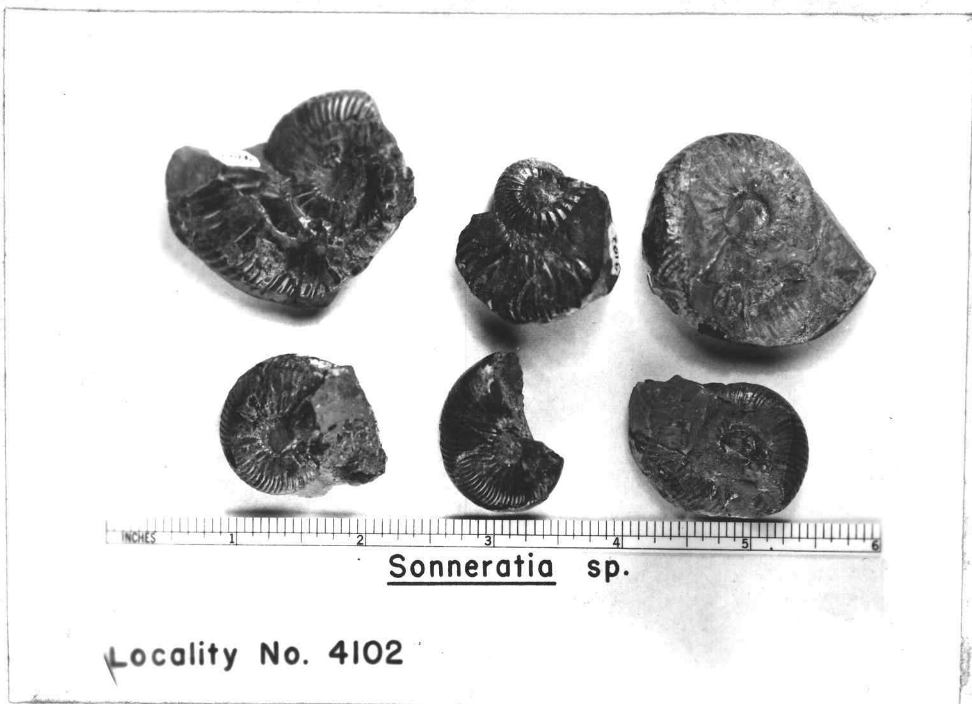


Figure 16. Sonneratia sp., collected from the Frizzell shale unit.

the middle of the shale unit, but no collections were made.

Packard (23, p. 296) has collected extensively from the lower shale in the Mitchell area and he states:

> "The lower shale member or formation has yielded a fauna rich in cephalopods with lesser numbers of pelecypods, brachiopods, echinoids, and crustaceans. The vertebrate fauna includes one Ichthyosaur and a specimen of pterosaur allied to Pteranodon. The ammonites include a number of wide-ranging and well-known species, such as Guadryceras sacya Forbes, Desmoceras voyi Anderson, and a number of California species of Sonneratia previously found only in the upper Horsetown. A group of three new species of an ancylocerid type are assigned to a new genus. Desmocerids are the most common forms, and are found by the hundreds in a rather restricted horizon traceable on both limbs of the Cretaceous structure, and for several miles along the strike. This group includes at least 8 new species.
>
> Eight species of the genus Sonneratia are found, of which three are considered new. Large lytocerids are present in the fauna, as are two species of Pervinquiera and a new species of Tetragonites. The 20 or more new species, together with the previously described species of the fauna, indicate that the lower shale fauna is most closely allied to the middle and upper Horsetown of California."

Origin and Conditions of Deposition. The unit contains marine fossils indicating that it accumulated as muds and sands in the sea. The absence of much sandstone in the lower and middle parts of the unit suggests uniform sedimentation and a low lying or distant landmass. Near the top of the unit, the sandstone becomes dominant, and this change from shale to sandstone probably reflects the effects of a rise of the source area during deposition. The thickness and nature of the sediments suggest that they were deposited in a geosyncline whose nature and extent are not known.

Relations and Age. The unit overlies the Basal Mitchell unit conformably and is overlain conformably by the Frizzell conglomerate unit. Packard (23, p. 296) has determined from fossil evidence that the shale was deposited during the middle and upper Horsetown stage. The age of the unit is, therefore, Lower Cretaceous.

Frizzell Conglomerate Unit

Distribution and Topographic Expression. This unit is widely distributed in the central and eastern sectors where its outcrops appear over an area of about 10 square miles.

The largest outcrops appear on both limbs of the Mitchell anticline as resistant, moderately dipping beds standing in marked relief above the underlying Frizzell shale. Where the unit is in contact with the overlying Clarno formation the conglomerate does not protrude topographically, as both units appear to be nearly equally resistant to erosion. This is expecially noticeable on the southeastern limb of the anticline. On the northern portion of the northwestern limb the Frizzell conglomerate crops out as northeasterly trending ridges, and in the central portion of the limb as tilted fault blocks. The southern part of this limb has been intruded by daçitic and andesitic intrusives which form the higher portions of some of the ridges. Several discontinuous beds of shale occur within the unit, and form valleys in the otherwise resistant conglomerate and sandstone.

An isolated outcrop of conglomerate occurs in the central portion of Sec. 16, T. 11 S., R. 21 E. This outcrop is about 4000 feet long and about 1200 feet wide, strikes east-west, and appears on both sides of Bridge Creek. The conglomerate forms an easterly-trending ridge on the upthrown side of an easterly-trending fault, and represents the western-most exposure of the Mitchell beds in the area.

Lithology. The unit is made up of three principal types of sediments. These are: (1) graywacke pebble conglomerate, (2) graywacke and sub-graywacke sandstone, and (3) shale. The unit is dominated by pebble conglomerate, as graywacke and sub-graywacke sandstone and shale appear only as interbedded lenses of limited to moderate extent.

(1) Graywacke pebble conglomerate. The principal rocks in the unit are well indurated graywacke conglomerates, ranging from granule conglomerates to pebble conglomerates. On the fresh surface the conglomerates range in over-all color from light olive gray (5Y 5/2) to grayish olive green (5GY 3/2). Pebbles of dark-colored basic igneous rocks and light-colored quartzite and chert in a matrix of graywacke sandstone give the rock this greenish gray appearance. On the weathered surface the color varies from grayish brown (5YR 3/2) to dark yellowish brown (10YR 4/2).

Weathering of the conglomerate causes a breakdown of the sandy matrix and results in an accumulation of loose pebbles at the base or on the surface of the outcrop. A few inches below the weathered surface fresh well indurated conglomerate is present. Differential weathering of the matrix results in the projection of the pebbles above the surface.

Along the Service Creek road in the central portion of Sec. 32, T. 10 S., R. 22 E., differential erosion along intersecting vertical joint planes has resulted in the formation of numerous pinnacles of conglomerate (Fig. 17). The joints trend N. 20° W. and S. 70° E., and appear to be spaced 5 to 10 feet apart. The pinnacles are 10 to 35 feet in height, 5 to 10 feet in diameter, and taper to a blunt point. Interbedded sandstone lenses cause slight identions in the pinnacles.

Bedding is thin to massive; the beds range in thickness from a few inches to 60 feet (Fig. 18). The attitude of the massive conglomerate layers is sometimes difficult to discern and can be determined only by the attitude of the interbedded sandstone. Typically, the conglomerate beds exhibit both a lateral and vertical gradation in pebble size. Where the conglomerate is in contact with a sandstone bed, the bedding plane is wavy.

On the outcrop the rock shows rounded to sub-rounded pebbles and an occasional cobble firmly imbedded in a matrix of graywacke sandstone. The following rock types are recognizable in the hand specimen: quartzite and chert; meta-volcanics, including metabasalt, greenstone, and serpentinite; meta-sediments, including dark-colored schist, phyllite, and slate; granitic rocks; vein quartz; and an occasional limestone pebble.

Quartzite pebbles are various shades of green, red, gray, and grayish black. They are generally fractured and healed with secondary silica. In the hand specimen the distinction between quartzite

Figure 17. Pinnacles of conglomerate exposed along the Service Creek Road.

Figure 18. Northerly dipping conglomerate and sandstone beds of the Frizzell conglomerate unit as exposed along the Service Creek Road.

and chert pebbles is difficult, but most quartzite pebbles are darker in color and in some specimens the individual quartz grains comprising the rock can be distinguished.

Chert pebbles generally show light shades of green, yellow, red, or gray. All of these colors may be present in a single pebble. The pebbles are hard and resistant and break with a splintery fracture. Many have been fractured and rehealed with vein quartz.

Meta-volcanic pebbles are grayish green to black. The constituents are usually not distinguishable in the hand specimen and so refinement in nomenclature is difficult. The metamorphic character of these rocks may not be apparent but under the microscope they are seen to be altered and metamorphosed aphanitic igneous rocks, for the most part meta-basalts. The grain size and texture are variable; many are porphyritic. Mafic minerals of these rocks have been converted to calcite, chlorite, serpentine, and epidote. Feldspar, principally labradorite, is partially converted to calcite and sericite. Chlorite and serpentine are estimated to make up 15 to 20 per cent of these rocks and are responsible for the greenish color observed in the hand specimen. The term greenstone seems appropriate.

Granitic types form only a small percentage of the pebbles. The granitic rocks appear to have a large percentage of dark minerals.

Meta-sedimentary pebbles are dark green to black and consist of slate, phyllite, and schist.

Less common are white vein quartz and occasional gray to grayish blue limestone pebbles. Pebbles of vein quartz are generally more angular than the others.

The composition and estimated percentages of the average of 294 conglomerate pebbles representing five samples are given below. Identification of the pebbles was made megascopically with the aid of a hand lens.

Pebble type	Per cent
Quartzite and chert	57
Basic igneous rocks, including greenstone, serpentinite, etc.	32
Meta-sediments, including slate, phyllite, schist	6
Granitic rocks	3
Felsitic igneous rocks	1
Other rocks, including limestone and vein quartz	1

An interesting feature of the conglomerate is the occurrence of generally rounded pebbles set in a matrix angular sandgrains (Fig. 19). This matrix makes up 10 to 35 per cent of the rock and has the following estimated composition:

Constituent	Per cent	Constituent	Per cent
Quartz and chert	40	Meta-sediments and meta-volcanic rock fragments	15
Calcite	20	Limestone fragments	3
Plagioclase	7	Intergranular detritus	10
Orthoclase	3		
Other minerals	2		

The presence of considerable secondary calcite in the matrix is noteworthy; however, only one slide was examined so the percentages may indicate only a local facies.

Veinlets of calcite are traceable from the matrix into some of the pebbles whereas veinlets of quartz commonly occur in the pebbles but are cut off at their contact with the matrix. In several instances the original quartz veinlets have been reopened and secondary calcite deposited along their centers contemporaneously with the deposition of secondary calcite in the matrix.

A compilation showing pebble size and type of five samples of the pebble conglomerate is shown in Tables 2 and 3 and the location of these samples is shown in Plate 3.

(2) Graywacke and sub-graywacke sandstone. Medium-grained marine graywacke and sub-graywacke sandstones are interbedded with the Frizzell conglomerate unit. They are well indurated and form resistant ridges where interbedded with shale and slight indentions where associated with conglomerate. On the fresh surface they are light olive gray (5Y 5/2), pale olive (10Y 6/2), or medium gray (N5) while on the weathered surface they vary in color from grayish brown (5YR 5/2) to dark yellowish brown (10YR 4/2). Differential weathering of the constituents results in a slight difference in relief between resistant quartz and chert fragments and the less resistant fragments.

Sandstone beds range in thickness from an inch or less to about 4 feet (Fig. 20). Graded bedding is present in some of the thinner beds. No cross-bedding was noted.

In the hand specimen rock fragments and quartz sand grains are visible along with an occasional small pebble. Some feldspar fragments are discernible, especially if kaolinized.

Microscopically the rock is seen to consist of rock and mineral fragments firmly cemented by a "paste" of clay, chlorite, and small quartz fragments (Fig. 21, 22). Table 4 shows the modes of

Table 2

Percentage of Pebble Types Comprising
Conglomerates in the Frizzell Conglomerate Unit

Pebble Type	Sample Number				
	0 00	15 00	56 00	75 00	77 00
Basic igneous rocks including greenstone, serpentinite, etc.	13	29	30	52	37
Quartzite and chert	83	63	47	29	58
Meta-sediments, including slate, phyllite and chert	4	7	13	9	-
Granitic rocks undifferentiated	-	1	5	5	5
Other rock types, including felsites, vein quartz and limestone	-	1	5	5	-
Number of pebbles examined	68	93	40	41	41

Table 3

Percentage of Pebble Sizes Comprising
Conglomerates in the Frizzell Conglomerate Unit

Pebble Size (in inches)	Sample Number				
	0 00	15 70	56 45	75 00	77 00
2	-	4	5	-	19
1.5-2	-	2	8	5	21
1-1.5	4	18	20	50	23
0.5-1	46	56	52	40	31
0.5-0.25	50	20	15	5	5
Number of pebbles examined	68	93	40	41	41

Figure 19. Photomicrograph showing matrix of a pebble conglomerate. Veined chert pebble on left. Crossed nicols, x25.

Figure 20. Steeply dipping sandstone interbedded with pebble conglomerate.

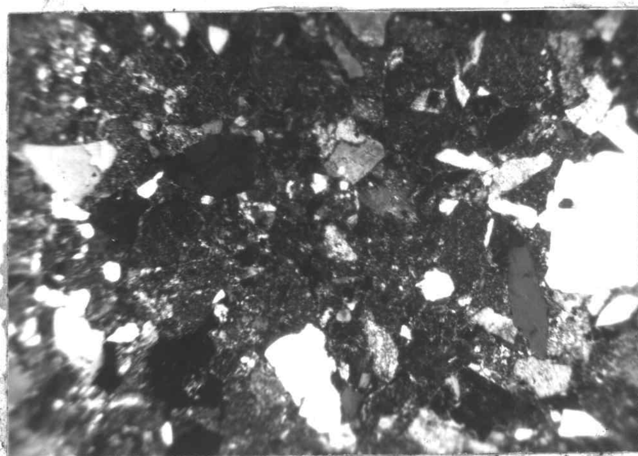


Figure 21. Photomicrograph of graywacke sandstone from the Frizzell conglomerate unit. Note angular rock and mineral fragments resting in a matrix of clay and chlorite. Crossed nicols, x25.

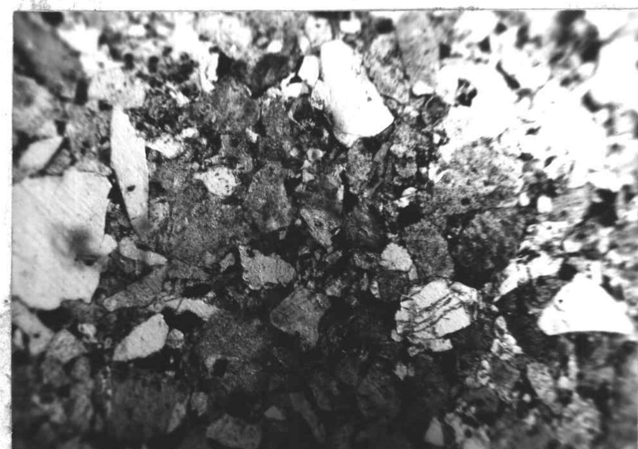


Figure 22. Photomicrograph of graywacke sandstone. Plain light, x25.

Table 4

Estimated Percentage Composition of 7 Graywacke or Sub-Graywacke Sandstones in the Frizzell Conglomerate Unit

Constituent	Sample Number						
	3 00	5 55	8 40	19 19	27 46	35 00	75 00
Quartz and chert	41	32	42	44	43	36	32
Plagioclase	7	1	5	10	10	6	1
Orthoclase	5	2	3	3	3	4	1
Calcite	T*	T	1	20	T	T	T
Zircon	T	-	T	Tr	T	T	-
Sphene	T	-	-	-	-	T	T
Magnetite	T	T	1	T	1	1	1
Limonite	T	T	T	T	T	T	T
Biotite	T	T	-	T	3	1	1
Epidote	T	T	-	T	T	T	2
Orthopyroxene	T	-	-	-	-	-	-
Apatite	-	-	T	-	-	-	-
Hornblende	-	-	-	-	-	-	T
Augite	-	-	-	-	-	T	-
Sericite	T	T	T	T	T	T	T
Quartzite	2	2	2	2	1	1	1
Limestone	3	T	1	1	1	-	T
Meta-sediments and meta-volcanics	26	16	25	10	23	33	46
Intergranular detritus (principally clay and chlorite)	15	47	24	10	16	18	15

* Trace; present in amounts less than 1%.

seven sandstones examined microscopically. Sample numbers refer to the location of the sample in the measured section. The average composition of the seven slides examined is given below:

Constituent	Per cent	Constituent	Per cent
Quartz and chert	38	Meta-sediments and meta-volcanic rock fragments undifferentiated	28
Plagioclase	6	Limestone	1
Calcite	3	Intergranular detritus (chlorite, clay, etc.)	23
Orthoclase	2		
Biotite	T		
Other	1		

The sandstones are poorly sorted as the constituents range in size from less than 0.1 mm. to 2 mm.

Angular to sub-rounded quartz and chert fragments comprise about 38% of the average sandstone examined. Unidentified inclusions in the quartz fragments are common and many of the fragments show strain shadows under crossed nicols and give a slightly biaxial interference figure. Vein quartz is present in a few grains and is characterized by flamboyant and lamellar structure. Chalcedony is rare.

Feldspar is estimated to make up 9 per cent of the average sandstone. Of the feldspar, two-thirds are plagioclase. Oligoclase and labradorite were recognized in the thin section by their extinction angles and their indices of refraction in comparison with that of balsam. Basic plagioclase is most common and shows distinct albite twinning. Orthoclase is less common and is somewhat altered to kaolin.

Calcite is estimated to form 3 per cent of the slides examined. It is secondary and occurs only in the matrix.

Meta-sedimentary and meta-volcanic fragments are estimated to make up 27 per cent of the sandstone. No attempt was made to differentiate these fragments into definite rock types, but greenstone, serpentinite, altered felsitic rocks, quartzite, schist, and slate were noted.

In addition to these constituents, the following minerals were noted: biotite, zircon, titanite, magnetite, pyrite, hornblende, augite, apatite, and orthopyroxene. Secondary minerals distinguished include epidote, limonite, chlorite, sericite, and kaolin.

Intergranular detritus comprises about 23 per cent of the average sandstone and consists of a greenish to greenish-yellow "paste" of clay, chlorite, and quartz, enclosing and firmly cementing the rock and mineral fragments.

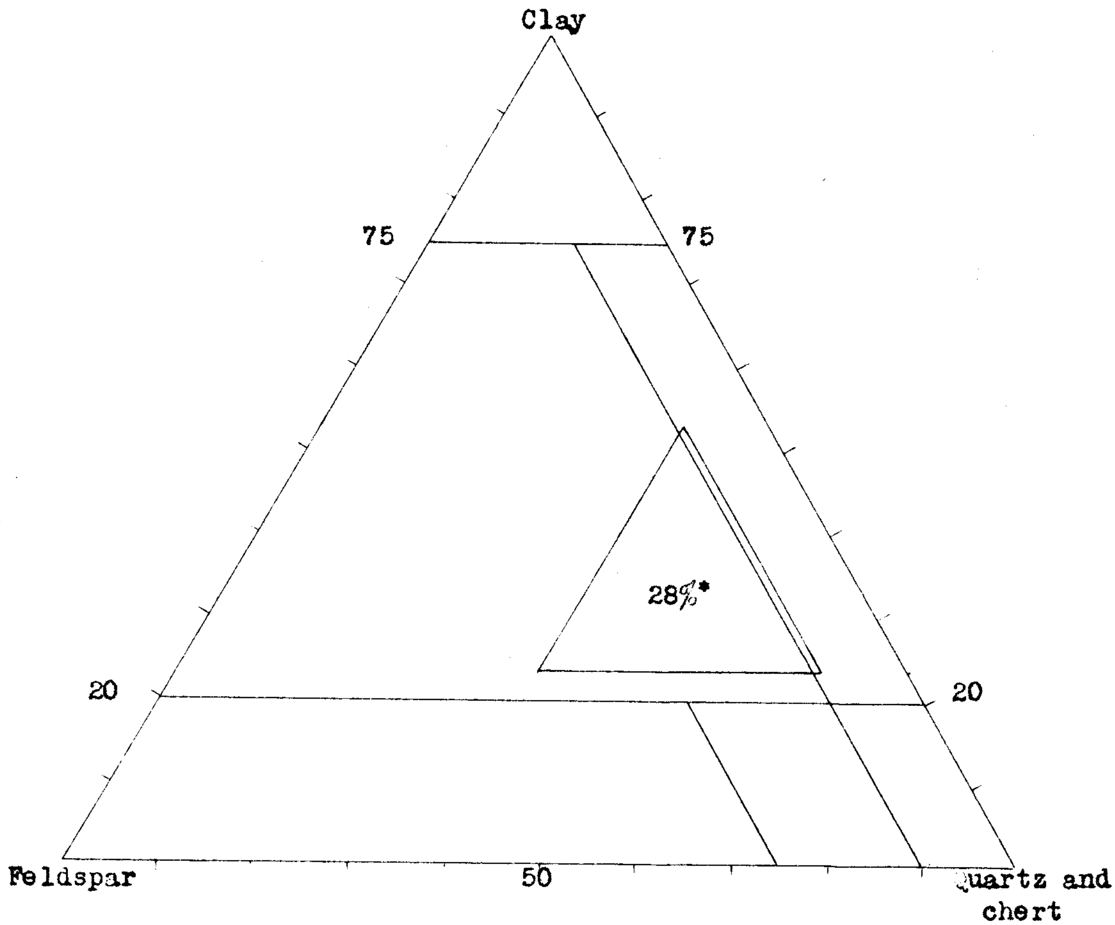
A triangular diagram of an "average" sandstone corresponding to the percentages given on page 50 is shown in Table 5. It is constructed after a method presented by Pettijohn (24, p. 228). Table 6 shows the plots of the individual samples on a similar diagram.

(3) Shale. Shale occurs as discontinuous lenses within the unit and is quite similar in appearance to the shale in the Frizzell shale unit previously described. No fossils were noted in these shales.

<u>Thickness</u>. The thickness of the Frizzell conglomerate unit varies considerably in the area. The unit has its maximum exposed

Table 5

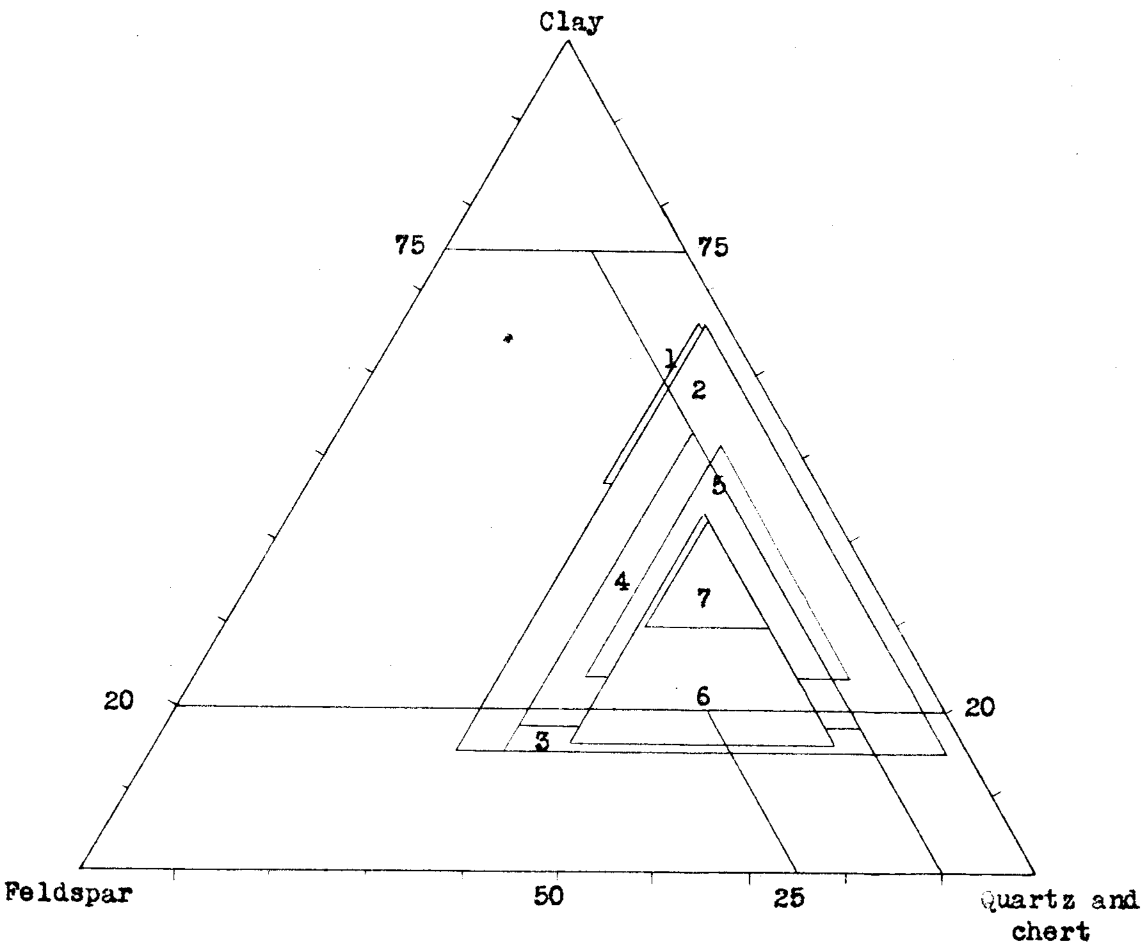
Triangular Diagram Of The "Average" Sandstone
From The Frizzell Conglomerate
Unit



* Percentage of rock fragments and accessory minerals.

Table 6

Triangular Diagram Of Seven Sandstones
From The Frizzell Conglomerate Unit



Explanation

No.	Sample No.	Name
1	5 55	Sub-graywacke sandstone
2	75 00	Sub-graywacke sandstone
3	3 00	Graywacke sandstone
4	35 00	Graywacke sandstone
5	8 40	Sub-graywacke sandstone
6	27 46	Graywacke sandstone
7	19 19	Graywacke sandstone

thickness on the southeastern limb of the Mitchell anticline, where a section of massive pebble conglomerates, sandstones, and shales measures 3168 feet. On the northwestern limb the thickness is difficult to determine because of faulting, but is at least 2000 feet.

<u>Measured Section</u>. A section of this unit was measured using a steel tape, Brunton compass, and an aneroid barometer. The base of the section is located at an elevation of 3650 feet in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ NE. $\frac{1}{4}$, Sec. 16, T. 11 S., R. 22 E., where the Frizzell conglomerate unit conformably overlies the Frizzell shale unit. From this point the section runs generally southeast up the valley to the contact with the overlying Clarno formation at an elevation of 4300 feet in the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 21, T. 11 S., R. 22 E.

Outcrops along the section are generally good, with the exception of a gap of some 800 feet near the top which are obscured by soil and by talus from the overlying Clarno formation. The dip of the beds is fairly constant at about 20° in a southeasterly direction. The section is believed to be free from any major faulting.

The section is divided into 5 lithologic sub-units. The areal continuity of these sub-units was not demonstrated, but they serve as an illustration of the lithology in the immediate vicinity of the section, and in general, as an illustration of the lithology of the southeast limb of the Mitchell anticline. The sandstone and shale beds encountered in the section may be traced laterally for a short distance, usually less than ½ mile, before they pinch out.

The lowest stratigraphic sub-unit is designated as sub-unit 1, and consists of about 340 feet of massive pebble conglomerate and interbedded sandstone, overlain by thin- to thick-bedded graywacke sandstone.

Sub-unit 2 has a thickness of about 250 feet and consists of shale and interbedded graywacke sandstone.

Sub-unit 3 consists of about 1000 feet of massive pebble conglomerate layers and interbedded graywacke sandstones.

Sub-unit 4 is about 300 feet thick and is made up almost exclusively of graywacke sandstone and some pebble conglomerate beds near the base.

Sub-unit 5, the upper-most sub-unit, consists of about 400 feet of pebble conglomerate and interbedded graywacke sandstone. Overlying these rocks are about 800 feet of covered material probably consisting of conglomerate with interbedded graywacke sandstone.

The total thickness of the measured section is 3168 feet.

Plate 3 shows a generalized columnar section of the measured section.

The measured section of the Frizzell conglomerate unit is as follows:

Sample number	Field description	Thickness (in feet)	Cumulative thickness (in feet)
77 00	Top of section. Conglomerate pebbles and sandstone fragments overlain by volcanic breccia. Contact concealed........	45	3168

Sample number	Field description	Thickness (in feet)	Cumulative thickness (in feet)
75 00	Thin- to thick-bedded, dark, well indurated sandstone. Occasional beds of pebble conglomerate 2 to 3 feet thick. Exposures are mostly grass-covered............................	45	3123
56 45	Massive pebble conglomerate. Poor exposures, traceable only by conglomerate pebbles.................	1110	3078
42 00	Pebble conglomerate grading upward into coarse angular sandstone which grades into a medium-grained, medium-bedded sandstone...	290	1968
41 53	Interbedded sandstone and pebble conglomerate. Sandstone dominant with beds 1 to 2 feet thick.............................	20	1678
35 00	Massive pebble conglomerate with interbedded sandstone layers 1 to 2 feet thick.......................	480	1658
29 42 27 46	Pebble conglomerate with interbedded green to yellowish gray sandstone.........................	80	1178
23 25	Massive pebble conglomerate with interbedded sandstone. Shows much variation in pebble size, but average size is estimated to be 1 to 1.5 inches in diameter..........	234	1098
19 91	Medium-bedded, greenish gray sandstone with occasional thin partings of dark gray shale. Weathering of the sandstone is more pronounced than elsewhere.............	80	864
19 91	Massive pebble conglomerate. Outcrop partially obscured by vegetation. Interbedded sandstone............................	180	784

Sample number	Field description	Thickness (in feet)	Cumulative thickness (in feet)
16 00	Grit. Dark yellow gray, somewhat less resistant than the underlying pebble conglomerate..........	2	604
15 70	Ridge-forming massive pebble conglomerate. At the base is a layer 3 feet thick with cobbles as much as 5 inches in diameter, grading upward into a conglomerate composed of pebbles 1 inch in diameter. Interbedded yellowish gray sandstone is common and forms beds 6 to 12 inches thick..........	12	602
13 00	Dark gray to greenish gray shale with poor fissility. Sandstone lenses are interbedded. Shale shows local variation in attitude but generally dips to the southeast about 20°....................	250	590
8 40	Sandstone. Beds 1 to 4 feet thick. Sandstone is medium-grained, grading upward to a silty sandstone....................	25	340
5 65	Pebble conglomerate with interbedded sandstone. Conglomerate forms a resistant ridge. Size of pebbles ranges from $\frac{1}{2}$ to 1 inch in diameter.................	15	315
3 00	Thin- to medium-bedded, greenish gray to brown, well indurated sandstone. Bedding planes are smooth with beds 4 to 12 inches thick. Layers of dark gray shale 1/16 to 1/2 inch thick are interbedded....................	110	220
0 00	Base of section. Massive pebble conglomerate with interbedded sandstone lenses 1 to 2 feet thick. Conglomerate is brown on weathered surface. Pebbles rounded to subrounded with an average size from		

Sample number	Field description	Thickness (in feet)	Cumulative thickness (in feet)
	1 to 1.5 inches in diameter. Some cobbles as much as 6 inches in diameter are present. Pebbles are quartzite, chert, meta-sediments, meta-volcanics, granitic, and felsitic rocks....................	110	110

Paleontology. Fossils are rare within the unit and none was found "in situ." Fossiliferous float (Fig. 23) was found just beneath the contact of the Frizzell conglomerate unit and the Frizzell shale unit in the SW. $\frac{1}{4}$, Sec. 10, T. 11 S., R. 22 E. The O. S. C. fossil locality number is 4101 and is plotted on the geologic map. McIntyre (35) has reported a similar faunule from a locality near Marshall Butte.

A list of the faunule from locality 4101 is given below:

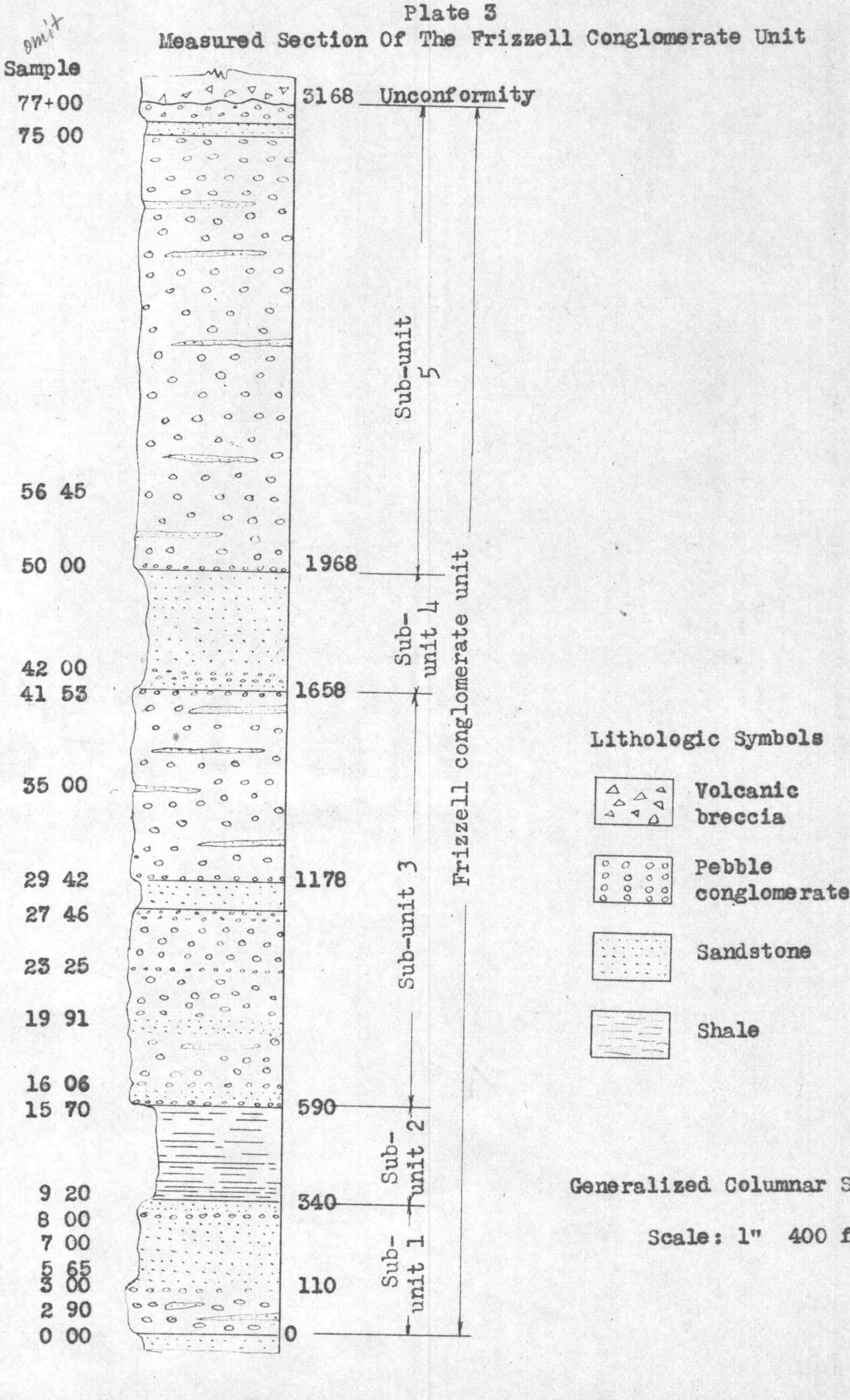
Anomia cf. vancouverensis Gabb, "Pal. Cal.," Vol. 11, 1869, p. 202, pl. 33, fig. 102.
Idonarca sp.
Leda sp.
Mytilus sp.
Solen sp.
Spisula sp.
Syncyclonema cf. operculiformis Gabb, Stewart, Acad. Nat. Sci., Phila., Spec. Pub. No. 3, 1930, pp. 120-121.
Tellina sp.
Triconocallista (?) sp.
Trigonia deschutesensis Packard, "The Trigoniae from the Pacific Coast of North America," 1921, p. 24, pl. 10, fig. 3.

Crepidula sp.
Dentalium sp.
Natica sp.

Baculites sp.

Plate 3

Measured Section Of The Frizzell Conglomerate Unit



Generalized Columnar Section

Scale: 1" 400 feet

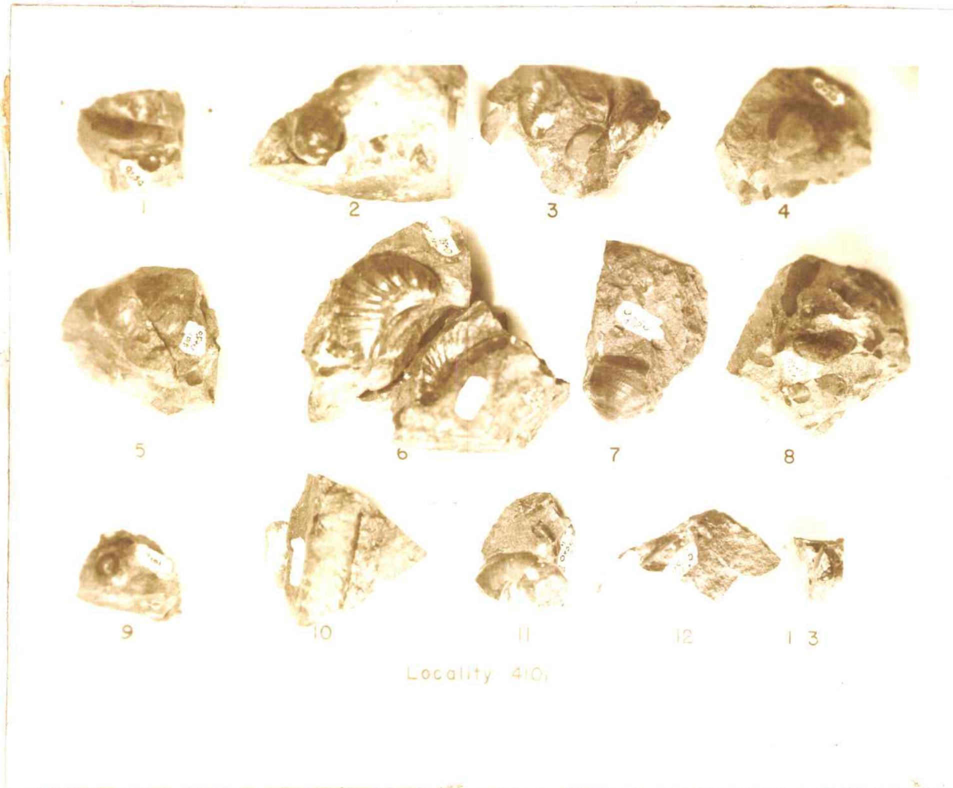


Figure 23. Faunule from the Frizzell conglomerate unit.

1 Solen sp.
2 Anomia cf. vancouverensis Gabb
3 Mytilus sp.
4 Syncyclonema cf. operculiformis
5 Idonarca sp.
6 Trigonia deschutesensis Packard
7 Triconocallista sp.
8 Tellina sp.
9 Natica sp.
10 Baculites sp.
11 Crepidula sp.
12 Dentalium sp.
13 Natica sp.

Origin and Conditions of Deposition. The unit accumulated as gravels, sands, and muds in a geosyncline. Marine invertebrate fossils preserved within the unit indicate that it accumulated in the sea. Rapid dumping and burial of the material are indicated by the poor sorting, presence of a clay matrix, angularity of grain, and feldspar content of the sandstone, and by the massive lenticular and polymictic nature of the conglomerate. Mechanical weathering was evidently the main process in the erosion of the source rocks as shown by the presence of considerable feldspar in the sandstone and in the matrix of the conglomerate. Pettijohn (24, p. 254), and Krumbein and Sloss (16, p. 132) regard graywacke and sub-graywacke sandstones and conglomerates as typical geosynclinal deposits. Further evidence of rapid deposition in a subsiding basin is the presence of graded bedding in some of the sandstone, as well as the absence of cross-bedding and ripple marks which if present would tend to indicate moderately slow accumulation of the sediments.

The polymictic nature of the conglomerate reveals that the source area was composed of a variety of rock types, including meta-igneous and meta-sedimentary types, granitic and felsitic rocks, and possibly older conglomerates. The meta-basalt pebbles are of special interest because they tend to indicate that the source area may have been the site of a former Paleozoic or Mesozoic geosyncline, in the terminology of Kay (15, p. 1289-1293) a "eugeosyncline."

Periodic uplift of the source area is reflected in the lithologic sequence observed in the measured section previously described.

The lithology of this section suggests that at least three uplifts occurred during the deposition of the material.

It is thought that the Frizzell conglomerate unit represents the last recorded marine deposits in a geosyncline of unknown nature and extent which had persisted during the deposition of the Frizzell shale and Frizzell conglomerate units.

Stratigraphic Relations and Age. The Frizzell conglomerate unit conformably overlies the Frizzell shale unit and is overlain unconformably by the Clarno formation. It contains marine invertebrate fossils including *Trigonia deschutesensis* Packard and *Baculites* sp.

Baculites is confined to the Upper Cretaceous in North America and *Trigonia deschutesensis* Packard has been placed by Packard in the "Upper Cretaceous, Chico group."

Merriam (19, p. 284) reported the similarity of the conglomerate at Mitchell to the conglomerate at Spanish Gulch, and concluded that the rocks were probably "Chico" in age.

Packard (22, p. 166) stated: "The coarser deposits higher in the section are undoubtedly of Chico age."

Both of these observations apparently were based upon the lithologic similarity between the conglomerates at Spanish Gulch and those at Mitchell. The discovery of a distinctive marine faunule in the conglomerate at Mitchell substantiates these earlier correlations.

The age, therefore, is Upper Cretaceous.

Pre-Tertiary Intrusive Rocks

1. Greenstone

Distribution and Topographic Expression. A small outcrop of greenstone about 60 feet wide and 150 feet long occurs on the west side of Meyers Canyon in the central part of Sec. 13, T. 11 S., R. 21 E., where it forms a resistant ridge extending to the canyon bottom.

Petrography. The outcrop is dark gray to brown and is characterized by intersecting, closely spaced fractures. The rock is very tough and difficult to break with the hammer, and on the fresh fracture has a dark greenish cast.

Under the microscope the rock is seen to be greatly altered and composed of laths of plagioclase feldspar, relics of olivine phenocrysts, magnetite, and the alteration products chlorite, serpentine, calcite, and "sericite." The mode of one specimen is as follows:

Constituent	Per cent	Constituent	Per cent
Labradorite	60	Serpentine	3
Olivine	6	"Sericite"	1
Magnetite	7	Hematite	T
Chlorite	15	Limonite	T
Calcite	8		

Plagioclase occurs as small laths, partly altered to calcite and "sericite". Olivine occurs as small phenocrysts crossed by a network of intersecting veinlets of chlorite and serpentine. The original mafic minerals, excluding olivine, have been entirely altered to serpentine or chlorite.

Relations and Age. The greenstone probably represents an intrusive in the older meta-sediments. The contact with the meta-sediments is not exposed and the actual relations are not known. Possibly correlative greenstone, probably Permian in age, has been reported by Taubeneck (28, p. 23) from the Dayville area.

2. Ultramafic dike rocks

Distribution and Topographic Expression. Ultramafic dikes occur on the east and west sides of Limekiln Creek in Sec. 1, T. 11 S. R. 22 E., as small resistant bodies 20 to 60 feet wide and as much as 300 feet long. The intrusives are tabular in outline and are greenish blue or greenish black on the outcrop. Along the margins of the dikes the intrusive rock is intensely fractured and slickensided. The material weathers into curved slabs, 3 to 5 inches thick and as much as 18 inches long.

Petrography. The rocks are serpentinites, serpentinized pyroxenites, and possibly serpentinized peridotites.

Microscopically the rocks are composed essentially of serpentine with a few relics of altered enstatite. Mesh-like networks of serpentine suggest that olivine was originally present. Turner and Verhoogen (29, p. 251) note that enstatite is not replaced by serpentine as easily as is olivine.

Calcite veinlets cut both the enstatite and serpentine.

Chromite occurs as small euhedral to subhedral crystals which appear brownish red on the thin edges. The mode of a specimen of pyroxenite is as follows:

Constituent	Per cent	Constituent	Per cent
Enstatite	30	Chromite	2
Serpentine	55	Calcite	6
Magnetite	7		

Although the petrogenesis of the rocks is not known, they possibly may be explained by the intrusion of a "peridotite magma" as outlined by Turner and Verhoogen (29, p. 251) who state: "Peridotite 'magmas' are composed largely of pyroxene and olivine crystals lubricated by interstitial magmatic liquid or water vapor. Serpentinization approximates to an equal volume replacement and occurs at temperatures of perhaps 200-400°C."

Relations and Age. The age of these ultramafic dikes is not known. They cut the Tony Butte meta-sediments and one dike appears to be cut by a hornblende andesite intrusive of probable Eocene age. Taubeneck (28, p. 50) has reported ultramafic rocks of Triassic age in the Dayville area and Dawson (8, p. 24) has reported Triassic pyroxenites in the Birch Creek area in the Dayville quadrangle.

Tertiary Lavas and Sedimentary Rocks

1. General Statement

Tertiary lavas and sedimentary rocks are dominantly of volcanic origin and include the Clarno, John Day, and Columbia River Basalt formations. They will be discussed in this order.

2. Clarno Formation

Name. The Clarno formation was named by Merriam (19, p. 285) in 1901. He states: "Resting upon the Chico, near Mitchell, also showing typical exposures at Clarno Ferry, is a presumably Eocene formation, to which the name Clarno is given. This formation is made up entirely of tuffs, ashes, and lavas. In places it contains many plant remains and is apparently in part a fresh water formation."

Distribution and Topographic Expression. The Clarno formation is exposed on both limbs of the Mitchell anticline over an area of about 18 square miles on the map. On the northwestern limb the formation appears west and southwest of Bridge Creek, and in a narrow belt beginning east of Sargent Butte and extending northeasterly to the vicinity of Hill 4300 in the NE. $\frac{1}{4}$, Sec. 33, T. 10 S., R. 22 E.

On the southeastern limb the formation appears in the SE. $\frac{1}{4}$, Sec. 15, T. 11 S., R. 22 E., and extends northeasterly to the eastern flank of Tony Butte.

West and southwest of Bridge Creek, well dissected, northerly-dipping basalt flows stand in relief above the less resistant tuffs of the John Day formation. Deep, steep-sided valleys and rounded to flat-topped ridges which form dip slopes to the north are typical of the topography (Fig. 24). In the vicinity of B.M. 2131, north of Bridge Creek, five small erosional remnants of basalt appear, completely surrounded by the John Day formation.

East of Bridge Creek and south of Meyers Canyon are six flows of basalt dipping 15° to the northwest. Individual flows are readily distinguishable, each being about 80 feet thick.

North of Meyers Canyon basalt flows and andesitic breccias form a series of northeasterly-trending ridges, with dip slopes to the northwest (Fig. 25). In the north central part of the area this belt of rocks forms rounded ridges and intervening steep-sided valleys.

In the eastern sector andesitic volcanic breccias and mud-flows are overlain by more resistant basaltic and andesitic flows (Fig. 26). Topographically this region is characterized by deep valleys, rounded ridges, and knoblike hills on the crests of some ridges.

Lithology. In this area the Clarno formation is composed mainly of volcanic rocks and consists of flow breccias, mudflows, tuffs, and flows of basalt, andesite, and dacite. In general, flow breccias, mudflows, and tuffs occur near the base of the formation, overlain by basalts, andesites, dacites, and associated tuffs. There are many exceptions to this sequence and great diversity occurs within the formation.

In detail the rocks within the formation may be divided into six petrographic types: (1) flow breccias and mudflows; (2) tuffs; (3) fine-grained basalts; (4) porphyritic basalt, including basalt, hypersthene basalt, hypersthene biotite-bearing basalt, quartz-bearing hypersthene basalt, biotite-bearing basalt, biotite-bearing

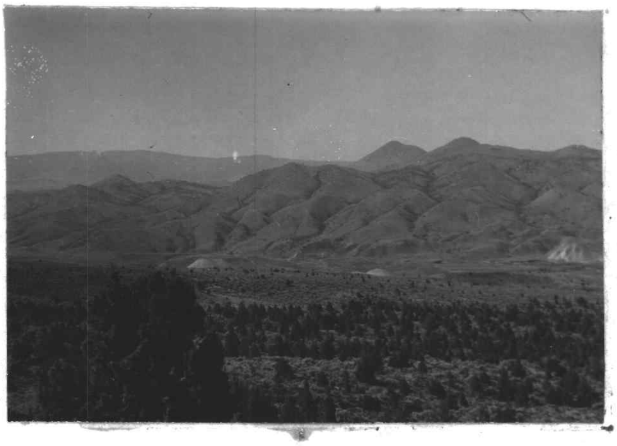


Figure 24. Northerly dipping Clarno basalt flows exposed south of Bridge Creek.

Figure 25. Clarno basalt flows exposed at the mouth of Meyers Canyon. Sutton Mountain in the background.

amphibole basalt, and amphibole basalt; (5) porphyritic quartz-bearing andesite; and (6) glassy dacite or andesite.

While attempting to unravel this diversity of rock types, several reconnaissance traverses were paced along selected traverse lines. These traverse lines are shown on Plate 2 and are numbered 1 to 6. In the following discussion these traverses will be referred to by number.

Samples were taken along these traverses where an obvious change in lithology occurred, and these samples were studied petrographically. Plate 4 shows the generalized results of this study. Tables 7 and 8 show the modes of some of the rocks studied and Table 9 shows the classification and location of the rocks presented in Tables 7 and 8.

(1) Flow breccias and mudflows. These rocks are generally restricted to the lower part of the formation and lie unconformably upon older rocks. Their thickness changes rapidly along the strike and in several instances basalts are interbedded or underlie them.

Andesitic volcanic breccias are more common than the mudflows and east of Tony Butte they underlie mudflows. Outcrops are massive in appearance and stand in nearly vertical cliffs at some localities (Fig. 28). The rocks consist of angular fragments of gray, green, yellow, and pink hornblende andesite fragments in a matrix of grayish green to yellow hornblende andesite, which contains euhedral to subhedral hornblende crystals as much as ½ inch long. Fragments of hornblende andesite are commonly 1 to 3 inches wide and are quite

Plate 4

Generalized Lithology Along Six Paced Traverses Of The Clarno Formation

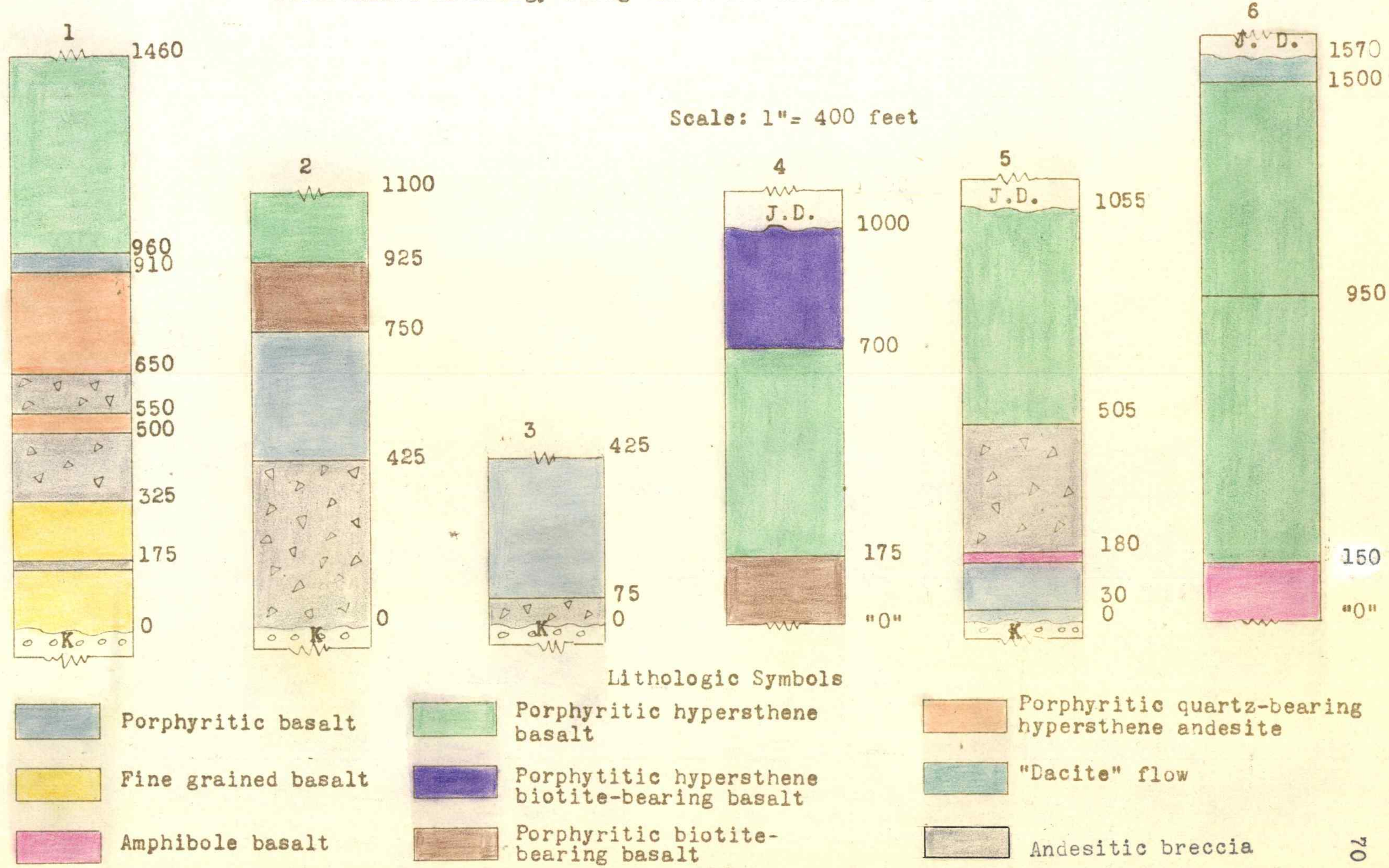


Figure 26. Clarno basalt flows overlying andesitic breccias on the east side of Limekiln Creek.

Figure 27. Outcrop of a mudflow exposed east of Tony Butte. Note the angular fragments of hornblende andesite in a tuffaceous matrix.

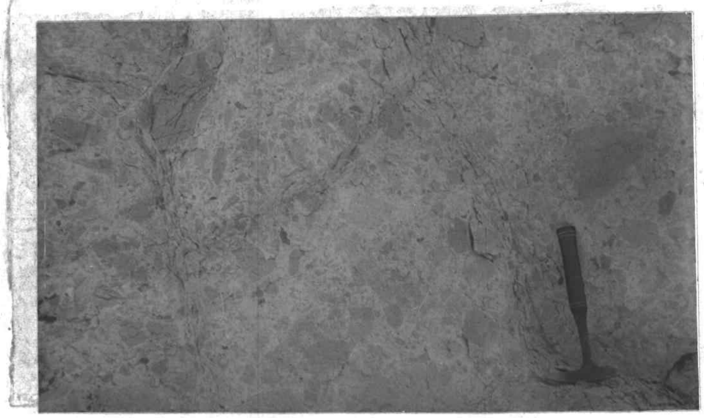


Figure 28. Exposure of andesitic flow breccia near the mouth of Rattlesnake Creek.

Table 7

Modes of Clarno Volcanic Extrusive Rocks

Mineral	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Percentages										
Andesine	-	-	62	-	-	-	-	-	-	-	-
Labradorite	65	56	-	60	65	66	66	65	54	64	65
Biotite	T*	-	-	-	-	-	3	-	-	2	T
"Lamprobolite"	-	-	-	-	-	-	-	-	-	T	-
Augite	20	10	11	10	16	15	15	15	15	12	18
Hypersthene	-	-	15	-	15	-	-	12	-	3	5
Quartz	-	-	2	-	-	-	-	-	-	-	-
Titanite	-	-	-	-	-	-	-	-	T	-	-
Magnetite	7	12	8	7	3	15	6	5	5	7	7
Apatite	-	-	T	-	T	-	T	T	T	T	-
Limonite	1	1	T	T	1	1	1	T	1	1	T
Chlorite	T	-	2	T	T	1	1	1	3	2	1
Calcite	1	-	-	-	-	-	T	T	T	-	-
"Sericite"	T	T	T	T	T	T	T	T	T	T	T
Epidote	-	-	-	-	-	-	T	-	-	-	-
Hematite	1	1	-	3	-	2	-	-	-	3	1
"Zeolites"	-	-	-	-	-	-	-	-	2	-	-
Glass	5	20	-	20	T	-	8	2	20	6	3

* Trace; present in amounts less than 1%.

Table 8

Modes of Clarno Volcanic Extrusive Rocks

Mineral	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	Percentages							
Labradorite	62	70	72	66	58	61	41	45
Biotite	-	1	-	1	-	-	-	2
"Lamprobolite"	-	-	-	20	-	-	25	-
Augite	25	20	20	-	25	20	-	30
Hypersthene	1	-	-	-	10	12	-	6
Quartz	-	-	-	T*	-	-	4	2
Titanite	-	-	T	-	T	-	-	-
Magnetite	6	4	6	2	4	5	5	5
Apatite	T	-	T	T	T	T	-	T
Limonite	1	1	1	T	T	T	1	T
Chlorite	1	2	1	8	3	1	5	3
Calcite	-	-	-	2	T	-	15	-
"Sericite"	T	T	T	T	T	T	T	T
Epidote	-	-	-	-	T	-	T	T
Hematite	1	-	-	-	-	-	-	-
Zeolites	-	-	-	-	-	-	4	-
Glass	3	2	-	-	T	1	-	7

* Trace; present in amounts less than 1%.

Table 9

Classification and Location of Rocks in
Tables 7 and 8

No.	Rock Name	Sample No.	Traverse
(1)	Fine-grained basalt	80-X	1
(2)	Fine-grained basalt	81-X	1
(3)	Porphyritic quartz-bearing andesite	83-X	1
(4)	Porphyritic basalt	85-X	1
(5)	Porphyritic hypersthene basalt	86-X	1
(6)	Porphyritic basalt	73-X	2
(7)	Porphyritic biotite-bearing basalt	74-X	2
(8)	Porphyritic hypersthene basalt	75-X	2
(9)	Porphyritic basalt	X-79	3
(10)	Porphyritic hypersthene biotite bearing basalt	X-255	4
(11)	Porphyritic hypersthene basalt	X-257	4
(12)	Porphyritic hypersthene basalt	X-257A	4
(13)	Porphyritic biotite-bearing basalt	X-258	4
(14)	Porphyritic basalt	96-X	5
(15)	Porphyritic biotite-bearing amphibole basalt	97A-X	5
(16)	Porphyritic hypersthene basalt	X-265	5
(17)	Porphyritic hypersthene basalt	X-26A	6
(18)	Amphibole basalt	X-26	6
(19)	Porphyritic quartz-bearing hypersthene basalt	X-22	6

angular. When the breccia is broken, it breaks across these fragments. The weathered surface is yellowish gray and much of the surface of the outcrop is rough and jagged where fragments protrude.

As the junction of fragments with the matrix is not sharply defined, the broken material may have been fused on the edges by the less viscous lava before final consolidation of the flow.

Material interpreted as former mudflows was noted in the area due east of Tony Butte (Fig. 27) and southeast of Hill 2707 in Sec. 11, T. 11 S., R. 21 E. At both localities the material consists of subangular to angular fragments mostly of gray, pink, green, and yellow hornblende andesite and occasionally of basalt embedded in a matrix of grayish to yellowish andesitic tuff. Lenses of thinly bedded waterlaid silts are present and testify to the presence of water in the material at the time of deposition.

The outcrop is gray to yellow gray. Boulders and fragments as much as 18 inches in diameter were observed but the average size of the fragments is about 2 inches. McIntyre (35), working in the southeastern part of the quadrangle, has reported boulders of hornblende andesite as much as 8 feet in diameter, and blocks of Cretaceous conglomerate as large as 10 feet in diameter.

(2) Tuffs. Chocolate brown, yellow, red, and grayish tuffs occur within the formation. They are andesitic in character and are usually interbedded with basalts or andesites. Good exposures occur east of Sargent Butte near Bridge Creek and along the northeasterly trending ridge northwest of Meyers Canyon. On the ridge northwest

of Meyers Canyon the tuffs are interbedded with porphyritic hypersthene basalts and have an estimated thickness of about 100 feet. They are poorly indurated and weather easily to a brown, yellow, or red soil. The material is sticky when wet and greatly resembles the John Day tuffs.

In the vicinity of Hill 4300 in Sec. 33, T. 10 S., R. 22 E., grayish white to yellowish waterlaid tuffs occur interbedded with basalts. They contain poorly preserved leaf impressions, petrified wood, and very thin layers of lignite. The maximum thickness of the tuffs as scaled from the map is about 500 feet. The tuffs weather readily and much of the surrounding area is covered by paper-thin chips of the material.

(3) Fine-grained basalt. Fine-grained, non-porphyritic basalts were observed only in the eastern part of the area, where they underlie andesitic volcanic breccias. They are poorly exposed and have a maximum thickness estimated to be 300 feet. In the vicinity of traverse 1, they lie unconformably upon the Frizzell conglomerate unit. Near the base the basalts are dusky brown (5YR 2/2) on the weathered surface and dark gray (N3) on the fresh fracture.

Under the microscope the rock shows a trachitic texture and exhibits flow structure (Fig. 29). It is very fine-grained and is composed of microlites of labradorite, small prismatic crystals of augite, light-colored glass, considerable magnetite, and minor amounts of limonite, hematite, calcite, and chlorite. Much of the magnetite crystallized at a late stage, and forms stringy aggregates interstitial to the plagioclase. The mode of the rock appears in Table 7 under (1).

Higher in the section the basalt contains more glass and the outcrop is lighter in color. On the fresh fracture the rock is grayish red (5R 4/2), with small areas showing a light greenish color caused by an unidentified amorphous alteration product.

Microscopically the rock has a hyalopilitic texture and contains about 20 per cent of light-brown glass containing numerous crystallites. The mode appears in Table 7 under (2).

(4) Porphyritic basalts. Porphyritic basalts are common in the formation and seven types are recognized. These types are not distinctive in the hand specimen and a microscopic study is essential in their recognition.

Porphyritic basalt. This rock is rather common near the base of the formation, usually overlying volcanic breccias or mudflows, although in the vicinity of traverse 5 it is overlain by these rocks. Individual flows are not discernible but in the four traverses in which the rock was encountered it varied in estimated thickness from 50 to 350 feet. On the outcrop the rock is jointed and fractured; platy jointing at intervals of ½ to 3 inches characteristic of the rock. The outcrop shows various shades of light brown, grayish black, and light red, while on the fresh fracture at least four colors are common including grayish black (N2), medium dark gray (N4), brownish gray (5YR 4/1), and pale red (5R 6/2).

Microscopic examination shows a porphyritic texture with phenocrysts of labradorite and pale green augite resting a pilotaxitic or hyalopilitic groundmass (Fig. 30). The groundmass contains as much as 25 per cent brown glass charged with dust-like particles of magnetite.

Labradorite occurs in two generations as euhedral to subhedral embayed phenocrysts and as small microlites. Augite occurs as pale green phenocrysts and as small prismatic crystals in the groundmass. Magnetite is present as small euhedral crystals and as stringy aggregates interstitial to the plagioclase in the groundmass. All sections examined show a variety of alteration products including limonite, hematite, chlorite, calcite, and "sericite." Modes of these basalts are given in Table 7 under (4), (6), and (9), and in Table 8 under (14).

Porphyritic hypersthene basalt and porphyritic quartz-bearing hypersthene basalt. These rocks usually occur near the top of the Clarno formation and were noted in five of the six traverses. They are quite uniform in appearance and composition and are the most common basaltic rock in the formation. At many places both the top and bottom limits of these rocks are exposed and they show a thickness varying from 525 to 1225 feet. Individual flows have an estimated thickness of 80 to 120 feet. The flows are well displayed north of Meyers Canyon and north of Sand Mountain and Sargent Butte, where they form dip slopes toward the north and northwest.

The basalts are platy near the tops of the flows. The outcrops show various shades of brown and dark gray, while the fresh

Figure 29. Photomicrograph of a fine-grained basalt from traverse 1. Note the aligned feldspar microlites and the presence of some glass. Crossed nicols, x25.

Figure 30. Photomicrograph of a porphyritic basalt from from traverse 3. Note phenocrysts of plagioclase feldspar resting in a groundmass of plagioclase, augite, and glass. Phenocryst of augite appears in lower-right corner. Crossed nicols, x 25.

fractures are grayish black (N2) or greenish black (5GY 2/1). With the aid of a hand lens, phenocrysts of plagioclase, augite, and occasional crystals of hypersthene are discernible.

Microscopically the rocks have a porphyritic texture with phenocrysts of labradorite, hypersthene and augite resting in a pilotaxitic groundmass of feldspar microlites, small prismatic crystals of hypersthene and augite, or augite along. Most of these rocks contain some brown glass, especially the quartz-bearing rocks. Much of the augite is glomeroporphyritic. Hypersthene occurs in some thin sections only as a phenocrysts but in others it is found in the groundmass as well. In one slide, hypersthene is enclosed by later augite. Modes of these basalts are given in Table 7 under (5), (8), and (11), and in Table 8 under (12), (16), (17), and (19).

Porphyritic hypersthene biotite-bearing basalt. This variety of basalt was observed only on the western edge of the area where it overlies the previously described porphyritic hypersthene basalt. The rock is deeply weathered and forms a more gentle slope than does the underlying hypersthene basalts. On the outcrop the rock shows various shades of grayish black and grayish brown, while on the fresh fracture it is olive gray (5Y 4/1). Phenocrysts of plagioclase and augite are visible as well as small brick red areas caused by the oxidation of iron-bearing minerals.

Microscopically the rock shows a porphyritic texture with phenocrysts of labradorite, hypersthene, and augite in a fine-grained groundmass of unoriented microlites of labradorite, small prismatic crystals of augite and hypersthene, and small shreds of dark brown biotite. Hypersthene and augite phenocrysts are embayed and partially resorbed and some are surrounded by rims of late magnetite. A mode of the rock is given in Table 7 under (10).

Porphyritic biotite-bearing basalt. Basalts of this type were noted both in the eastern and western parts of the area underlying porphyritic hypersthene basalts. At both localities the basalt is about 175 feet thick. It is light brown to reddish brown on the weathered surface and dark gray (N3) on the fresh fracture. In the hand specimen phenocrysts of light-colored plagioclase and dark green augite are visible. Oxidation of iron-bearing minerals causes small red spots on the surface of the rock.

Under the microscope the rock shows a porphyritic texture with phenocrysts of labradorite and augite in a pilotaxitic groundmass composed of labradorite, augite, and small shreds of biotite. Modes of two specimens appear in Table 7 under (7) and in Table 8 under (13).

Porphyritic amphibole basalt and porphyritic biotite-bearing amphibole basalt. These rather unusual rocks were found in traverses 5 and 6. In the vicinity of traverse 5 the rocks are exposed as a thin flow about 25 feet thick underlying volcanic breccia, while on traverse 6 they are more than 150 feet thick and lie beneath porphyritic hypersthene basalt. They are dark brown on the outcrop and brownish black (5YR 2/1) on the fresh fracture.

Phenocrysts of labradorite and the alteration products limonite and hematite are the only minerals visible macroscopically.

Microscopically the rocks are porphyritic, with phenocrysts of embayed and altered labradorite resting in a fine-grained groundmass of labradorite microlites and small dark brown pleochloric crystals of an amphibole resembling lamprobolite. In the biotite-bearing rocks, small brown shreds of biotite are present. Modes of these rocks appear in Table 8 under (15) and (18).

(5) Porphyritic quartz-bearing hypersthene andesite. Rocks of this type were found only in the eastern sector in the vicinity of traverse 1. There a flow 50 feet thick is interbedded in the breccia and several flows, totaling about 250 feet, overlie the breccia. As these flows are more resistant than the andesitic breccias, they stand in relief. On the outcrop the andesites weather to a light brown color while on the fresh fracture they are grayish black (N2). Striated plagioclase and the alteration products limonite and hematite are visible with a hand lens.

Microscopically the rock shows a porphyritic texture with phenocrysts of complexly zoned andesine and pleochloric hypersthene in a fine-grained groundmass of microlites of andesine and small prismatic crystals of augite. Hypersthene is in part resorbed, and has reaction rims of magnetite surrounding it. Quartz occurs as a late interstitial filling in the groundmass. A mode is given in Table 7 under (3).

(6) Glassy dacite or andesite. These rocks occur in the western part of the area where they are interbedded with and overlie basalts. They have an estimated thickness of about 70 feet and have only limited areal extent. On the outcrop the rocks have a pronounced eutaxitic structure, with alternating bands of light gray and light red material. The rock tends to be platy parallel to this structure and breaks easily into thin sheets 1/16 to 1/2 inch thick. On the weathered surface the rock is reddish brown while on the fresh fracture it is medium light gray (N6). In the hand specimen no minerals are visible and the material appears glassy.

Under the microscope, fragments of the material show that the rock is composed essentially of partially devitrified light-colored glass and minute microlites of plagioclase feldspar. The glass has an index of refraction of about 1.516, which according to Grout (11, p. 114) places the rock in the andesitic or dacitic range.

Generalizations on the Petrography of the Clarno Formation. With the exception of volcanic breccias and mudflows, the rocks are mostly fine-grained porphyritic basalts, andesites and dacites which are deeply weathered and only locally vesicular or scoriaceous.

Microscopically the rocks show porphyritic, trachitic, pilitic, and hyalopilitic textures.

Plagioclase usually occurs both as phenocrysts and in the groundmass and the phenocrysts generally show well developed albite twinning and are occasionally zoned, especially in the andesitic rocks. Both ortho- and clinopyroxenes occur. The clinopyroxene is pale green augite some of which is pigeonitic. Pleochloric hypersthene is the usual orthopyroxene. In some rocks clinopyroxene and orthopyroxene occur together but all gradations occur from hypersthene-free rocks to rocks in which hypersthene is dominant. The average hypersthene content of the rocks containing hypersthene is about 10% and the average augite content of rocks containing it is about 18%. Amphiboles are rare but a mineral resembling lamprobolite was observed. Olivine is conspicuously absent in all of the sections examined. Magnetite is the chief accessory mineral and occurs as early well formed crystals and as late stringy aggregates. The average magnetite content of the rocks examined is about 5%. Other accessory minerals include apatite, sphene, biotite, and quartz.

In thin section all rocks examined show evidence of late magmatic alteration and partial resorption of the early formed phenocrysts. Surface weathering has resulted in the formation of numerous alteration products including "sericite", chlorite, calcite, limonite, and hematite.

The order of crystallization shows considerable variation but the general sequence is magnetite and apatite, augite, hypersthene, plagioclase, late magnetite, quartz. Numerous exceptions occur; some hypersthene is earlier than augite and some magnetite is later than plagioclase. When present, quartz is late and interstitial to the other minerals.

Thickness. The exposed thickness of the Clarno formation as scaled from the map varies from about 3200 feet in the vicinity of Sand Mountain to about 1000 feet near Hill 2707, in Sec. 11, T. 11 S., R. 21 E. In the eastern sector the maximum thickness, as determined from paced traverses, exceeds 1400 feet.

Paleontology. The only fossil material found within the Clarno formation in this area was poorly preserved leaves and fossil wood from the tuffs in Sec. 33, T. 10 S., R. 22 E. No identification of this material was made.

Origin. The Clarno formation in this area is almost entirely of volcanic origin. Volcanic breccias and mudflows with interbedded basalts and associated tuffs are found near the base of the formation. The mode of origin of the volcanic breccias is uncertain, but they probably represent very thick flow breccias.

Waterlaid tuffs which occur near the base of the formation probably represent reworked volcanic ash which was swept into low spots in the topography.

The ash, volcanic breccia, and associated basalts covered the erosion surface which had developed near the close of the Cretaceous period. In view of the variations in the thickness of the deposits and in the diversity of rock types found near the base of the formation it seems reasonable that numerous volcanoes supplied these materials.

Locally some of the breccias consist of angular to sub-rounded fragments imbedded in a matrix of andesitic tuff containing lenses of reworked silt. This material may represent mudflows which occurred during periods of heavy rainfall. Breccias similar to those in the Mitchell area have been reported by Anderson (1, p. 215-275) from the Tuscan formation in northern California, where breccias 1100 feet thick are attributed by Anderson to mudflows.

Following the extrusion and accumulation of these breccias and flows, other lava flows were extruded and tuffs deposited. The porphyritic nature of most of the flow rocks, the diversity of their composition, and the resorption phenomena seen in thin section suggest that the rocks have had a complex magmatic history. As the individual flows have no soil zones preserved between them, either the flows were extruded in rapid succession without sufficient time between flows for the development of soil zones, or soil zones which had been developed were eroded away before the next flow occurred.

Field work was not comprehensive enough to determine any specific magmatic trend in the formation. In the broad sense, however, the formation appears to be dominantly andesitic in composition at and near the base and more basic toward the top. Locally interbedded dacitic material in the upper portions of the formation suggests that a more silicic phase developed after the basaltic extrusions. Such a phase also appears in the area to the east where Swarbrick (35) has reported extensive dacitic material. Wilkinson (33, p. 66) has described rhyolitic material in the Clarno formation in the vicinity of Mutton Mountain, and Waters et al. (32, p. 33) have reported rhyolites in the Horse Heaven district situated about

12 miles to the west of the area.

Relations and Age. The Clarno formation rests with angular unconformity upon the Frizzell conglomerate unit, the Frizzell shale unit, and the Tony Butte metasediments, and is overlain unconformably by the John Day formation. This relationship brackets the unit between the Frizzell conglomerate unit of Upper Cretaceous age and the Lower John Day of Upper Oligocene age.

Chaney (4, p. 348) has assigned the Clarno formation to the Upper Eocene on paleobotanical evidence.

Other authors have assigned the formation to the Lower Eocene, the Lower Oligocene, and the Lower Miocene. The United States Geological Survey, in 1938, assigned the Clarno formation, as originally defined, to the Lower Oligocene and Upper Eocene (31, p. 455).

3. John Day Formation

Name. The variegated tuffs in the John Day Basin were named the John Day formation by O. C. Marsh (18, p. 52) in 1875.

Distribution and Topographic Expression. This formation is quite extensive in the western part of the area and is exposed beneath the Columbia River basalt on Sutton Mountain, along Bridge Creek, and in the vicinity of the Painted Hills.

The formation forms low rounded conical hills along and near Bridge Creek and a dissected, gently sloping surface in the area between Sutton Mountain and Bridge Creek. Differential weathering of alternately hard and soft layers in the upper part of the formation results in intricate sculptured effects.

Lithology. In this area the John Day formation is composed of red, green, and buff tuffs and a welded tuff layer. Merriam (19, p. 293) divided the formation into three units: lower, middle, and upper. These divisions were made on the basis of color and vertebrate paleontological evidence. Calkins (2, p. 193) made a petrographic study of the formation and reported that the Lower John Day tuffs were trachitic, whereas the middle and upper tuffs were andesitic. Coleman (6, p. 27, 28), working in the Picture Gorge quadrangle, divided the formation into three major and two minor members. He states: "The three major members are (1) the lower red tuff beds, (2) the middle green tuff beds, and (3) the upper buff tuff beds. The two minor members are (1) local basaltic flows interbedded in the lower red beds and (2) the welded tuff bed separating the middle and upper tuff beds."

Beds similar to these three major members are present in the Mitchell area, along with a welded tuff layer.

The Lower John Day beds rest unconformably upon the Clarno formation and are well exposed along Bridge Creek. They are alternately brick red and buff or white and so the eroded outcrop has a striped appearance. Just west of the western boundary of the area, waterlaid white tuffs containing leaf impressions occur, suggesting that parts of the lower member are fluviatile in origin.

When wet the tuffs are sticky and upon drying the surface of the outcrop develops numerous small intersecting shrinkage cracks.

The middle John Day beds in this area are difficult to distinguish from the upper member on the basis of color. In Sec. 10, T. 11 S., R. 21 E., are exposures of green tuffs but in most of the area the tuffs overlying the red lower John Day beds are buff or show only a faint green color.

The green, buff, and light-colored tuffs are composed of alternately resistant and less resistant beds 2 to 6 feet thick, which upon weathering form a succession of projecting ledges and indentations. Fluted, intricately sculptured columns are developed in the softer material.

Overlying the greenish tuffs in Sec. 10, T. 11 S., R. 21 E., is a welded tuff layer with an estimated thickness of about 20 feet. Similar material about 50 feet thick overlies buff tuffs in the northern part of the Painted Hills, and continues north around the western edge of Sutton Mountain. In the Painted Hills region the welded tuff layer forms a dip slope to the north and northeast (Fig. 31). A layer about 50 feet thick is overlain by 10 feet of buff colored tuff which is in turn overlain by another 5-foot layer of welded tuff. Overlying the welded tuff at both localities are buff colored tuffs. The precise stratigraphic position of this welded tuff is not known but it appears to be interbedded within the middle John Day. Merriam (19, p. 294) states: "At Bridge Creek a rhyolite flow is interbedded with the lower part of the Middle John

Day or possibly separates it from the lower division." Many welded tuffs, as in this instance, have been mistaken for "rhyolite flows."

On the outcrop the material is chocolate brown, while on the fresh fracture it is light brown, light green, or nearly white. The welded tuff is generally hard although near the base it is punky. Macroscopically, pumice and rock fragments are seen to rest in a fine-grained tuffaceous matrix.

Microscopically the rock shows devitrified flattened shards of glass, collapsed pumice fragments, and angular rock and mineral fragments. The shards show a definite alignment and many are often wrapped around the rock and mineral fragments. The index of refraction of the glass is about 1.510-1.516, which according to Grout (11, p. 114) indicates a silicic glass of rhyolitic, dacitic, or andesitic composition.

The mode of a specimen from the middle of the layer in the Painted Hills region is given below:

Constituent	Per cent	Constituent	Per cent
Glass shards and pumice fragments.......	85	Quartz	1
Rock fragments	7	Plagioclase	T
Magnetite	1	Chlorite	6

The Upper John Day beds, as exposed beneath the Columbia River basalt formation on Sutton Mountain, are typically buff colored and consist of alternately hard and soft layers which form ledges and recesses with fluted and sculptured columns in the softer material. The general appearance of the outcrop is similar to that of the middle member.

Thickness. As scaled from the geologic map, the John Day formation has a maximum thickness of about 3100 feet. Merriam (19, p. 293) states: "At Bridge Creek....the section includes the whole of the series. It may reach a thickness somewhat over 2000 feet at that locality."

Paleontology. Extensive collections of vertebrate material from the John Day formation have been made by previous workers; however, no references to fossil localities within this immediate area were found in the literature.

Scraps of unidentified silicified bone were found in the Middle John Day beds in Sec. 10, T. 11 S., R. 21 E., and leaf impressions were noted in a white tuffaceous layer interbedded with the Lower John Day west of the area.

Origin. The origin of the John Day formation has recently been discussed in detail by Coleman (6, p. 123-129). He suggests that the formation represents aeolian and lacustrine deposits formed by the accumulation of ash blown from explosive volcanoes in the ancestral Cascades.

Some investigators have considered the formation to be entirely lacustrine in origin while others have favored an aeolian mode of deposition.

In the Painted Hills region, thinly bedded white tuffs in the Lower John Day beds suggest that at least part of these lower beds are lacustrine in origin. The tuffs higher in the section show no features characteristic of lacustrine deposition and are probably aeolian in origin.

The welded tuff probably represents a "nuees ardentes" type of deposit which was erupted from a local source during the accumulation of the Middle John Day beds.

Relations and Age. An angular unconformity separates the Lower John Day beds from the underlying Clarno formation. Columbia River basalt overlies buff tuffs of the Upper John Day along the southern face of Sutton Mountain.

The John Day formation is thus between the Clarno formation of supposed Eocene age and the Columbia River Basalt formation of Middle Miocene age. The middle and upper members have been assigned an age of Lower Miocene by Schultz and Falkenburg (26, p. 83), while the lower member has been referred to the upper Oligocene by Chaney (5, p. 22) on paleobotanical evidence obtained from the Bridge Creek flora.

Stock (27, p. 328) correlates the John Day formation with the continental Sespe formation of California.

4. Columbia River Basalt Formation

Name. This name was first used by Russell (25, p. 20) to describe Tertiary lavas which cover parts of Oregon, Washington, and northern Idaho. In the broad sense it includes lavas of Eocene, Miocene, and Pliocene age, but as used in this paper it is restricted to the Middle Miocene basalts.

Distribution and Topographic Expression. Exposures of Columbia River basalt occur on Sutton Mountain in the northern part of the area and in Sec. 6, T. 11 S., R. 22 E., and Sec. 1, T. 11 S., R. 21 E. The basalt on the southern face of Sutton Mountain forms a steep escarpment rising nearly a thousand feet above the underlying John Day formation. Nine individual flows are exposed on this face and at the top of the escarpment the uppermost flows form dip slopes toward the north (Fig. 32).

South of Hill 4680 in Sec. 1, T. 11 S., R. 21 E., Columbia River basalt flows, basalt boulders, and large angular blocks of basalt occur over an area of about 0.5 square mile. The material lies upon the Clarno formation, the Mitchell beds, and Lower John Day tuffs, and is interpreted, in part, as a landslide.

Lithology. On the southern face of Sutton Mountain individual flows are readily recognized and may be traced for a distance of at least four miles without interruption. The lowest flow has an estimated thickness of about 130 feet, and the overlying flow vary in thickness from 60 to 100 feet. The basal portion of the lowest flow is vesicular and amygdaloidal; it grades upward into a massive portion about 80 feet thick which has hexagonal columnar joints as much as 3 feet in diameter. The top of this flow is composed of scoriaceous basalt and a flow breccia consisting of angular fragments of basalt in a fine-grained matrix of the same material. The brecciated and vesicular material near the top of the flow is less resistant than the underlying massive basalt and is responsible for a

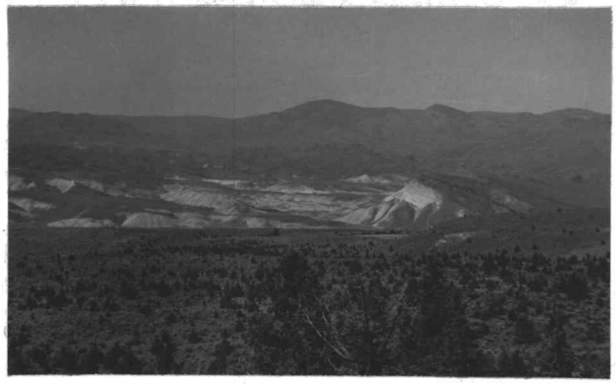


Figure 31. Welded tuff layer exposed in the Painted Hills region.

North Northeast

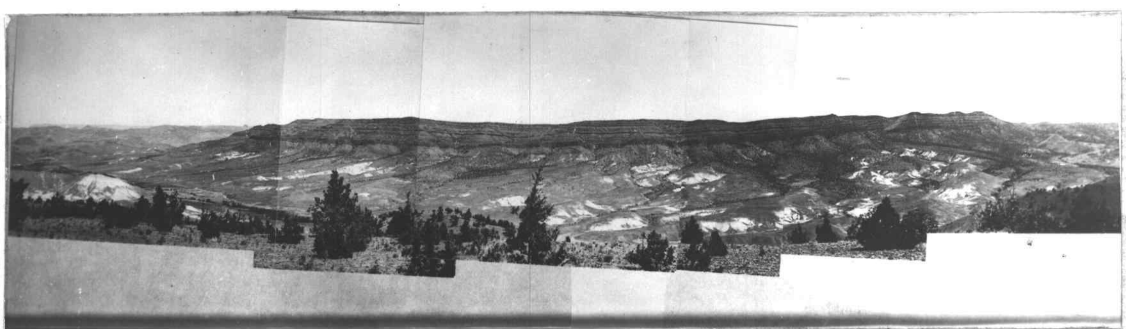


Figure 32. Panorama of Sutton Mountain. View shows resistant flows of Columbia River Basalt overlying the less resistant John Day formation. Note the easterly dip of the beds on left edge of photograph and the northerly dip of beds on right edge, indicating a syncline plunging to the northeast.

distinct break in the profile of the outcrop. This general sequence of resistant and weak portions is repeated flow by flow throughout the exposure. Vegetation, including grasses and an occasional juniper tree, grow in the non-resistant zones.

In the hand specimen the rock appears as a dark-colored aphanitic basalt. On the fresh fracture it is dark gray (N2) to black (N1), while on the weathered surface it shows various shades of brown. Laths of plagioclase feldspar and small crystals of yellowish to greenish olivine are distinguishable with the aid of the hand lens.

Several specimens from the lower flows on Sutton Mountain were studied microscopically. The rock is seen to be a fine-grained olivine basalt with textures ranging from ophitic to pilotaxitic. The mode of an ophitic type is given below:

Mineral	Per cent	Mineral	Per cent
Labradorite	48	Apatite	T
Augite	32	Chlorite	4
Olivine	10	Serpentine	2
Magnetite	3	Iddingsite	T

Augite and plagioclase are quite fresh in appearance and in the ophitic varieties the augite clearly encloses the plagioclase (Fig. 33). Large areas of the augite extinguish at the same time under crossed nicols.

Olivine occurs as subhedral, colorless, altered crystals and commonly shows a glomeroporphyritic arrangement. It is altered to chlorite, serpentine, and dark brown iddingsite. Olivine crystallized early as some of it is enclosed by augite.

Accessory minerals are magnetite and apatite. Some of the magnetite encloses small crystals of augite and olivine. The order of crystallization appears to be: magnetite and apatite, olivine, plagioclase, augite, late magnetite.

Thickness. As scaled from the geologic map, the Columbia River Basalt formation has a maximum thickness in the area of about 1200 feet.

Origin. It has been generally accepted that the Columbia River lavas are flood basalts which have been extruded from fissure type eruptions. The remarkable continuity and uniformity of the individual flows on Sutton Mountain indicate the low viscosity of the lavas at the time of their extrusion. Feeder dikes for these flows may be represented by several small dikes in Sec. 4, T. 11 S., R. 22 E., which have approximately the same mineralogical composition as the lavas.

Relations and Age. The Columbia River basalts lie upon the Upper John Day member. No angular discordance was detected between the John Day formation and the Columbia River basalt but an erosional unconformity is present. In this area no formation overlies the basalt, so it cannot be bracketed as to age. In the Dayville and Picture Gorge quadrangles the formation has been bracketed between the Upper John Day member and the Mascall formation by Coleman (6, p. 36) and Dawson (8, p. 66). As the Upper John Day is considered Lower Miocene in age and the Mascall formation is Upper

Miocene in age, the Columbia River basalt is placed in the Middle Miocene.

Lowry and Baldwin (17, p. 3) recently have stated: "The basalt is interbedded with the marine Astoria formation of Middle Miocene age in the lower part of the Columbia River Valley."

Quaternary Rocks

Quaternary rocks within the area are: (a) small terrace and floodplain deposits consisting of gravel, sand, silt and ash along Bridge Creek and the other streams, and (b) alluvial fans which have been deposited upon the John Day formation south of Sutton Mountain.

Valley alluvium reaches a thickness of about 70 feet in Meyers Canyon and is well exposed on the sides of the deep narrow channel which has been cut through the deposits by Meyers Creek. White ash deposits 6 feet thick occur within the alluvium and probably represent reworked material that was washed into the canyons during the accumulation of the alluvium. The source of the ash is not known.

Other alluvial deposits which are believed to be of Quaternary age extend from the base of Sutton Mountain almost to Bridge Creek and consist of loosely consolidated angular to sub-rounded boulders and smaller fragments which form a deposit as much as 12 feet thick overlying the John Day formation.

These deposits occur as scattered outcrops on a gently sloping surface which had been developed upon the John Day formation prior to their accumulation. Subsequent erosion has resulted in the dissection of the area, and the alluvial deposits are now restricted to the higher portions of some of the ridges. The deposits are interpreted as remnants of alluvial fans which were deposited upon the John Day surface by streams which flowed south from the Sutton Mountain area toward Bridge Creek during Quaternary time.

Tertiary Intrusive Rocks

1. General Statement

Intrusive rocks of Tertiary age include dacitic, andesitic and basaltic types, in the form of plugs, dikes, and sill-like bodies.

The age of these rocks is not definitely known but the majority appear to have been emplaced during or after the accumulation of the Clarno formation and before the deposition of the John Day formation. They are tentatively dated as Eocene or post-Eocene and pre-Upper Oligocene.

2. Dacitic Intrusives

Distribution and Topographic Expression. Dacitic intrusive rocks occur as plugs at Tony Butte; Sargent Butte; Sand Mountain; along the north limb of the Mitchell anticline in Sections 4, 8 and 9, T. 11 S., R. 22 E.; in Sec. 33, T. 10 S., R. 22 E.; and northeast and southwest of Meyers Canyon. Dacitic dikes occur northwest and southeast of Meyers Canyon.

Differential erosion of the plugs has resulted in prominent topographic features, Tony Butte being the largest and most imposing. The plugs are resistant circular, elliptical or irregular bodies standing in marked relief above the surrounding country rock.

Petrography. A variety of dacitic rocks are present and the main types are considered in the following order: (1) leuco-dacite porphyry, (2) dacite porphyry, (3) tourmaline-bearing dacite porphyry, (4)fine-grained dacite, type 1, and (5) fine-grained dacite and hyalo-dacite, type 2.

(1) Leuco -dacite porphyry. This rock was noted only at Tony Butte where it forms a roughly circular plug having a maximum diameter of about 1 mile and an area of about 0.8 square mile.

Systematic sampling was not undertaken but samples obtained near the top of the plug and at several localities on the margins show no appreciable differences in general appearance or composition.

The best exposures occur near the top of the plug, where the outcrop is massive in appearance and characterized by intersecting vertical and platy horizontal jointing (Fig. 34). The dacite spalls off in large roughly rectangular slabs as much as 7 feet wide and 2 feet thick which slide down the slopes and form rather extensive talus deposits. The rock is hard but rather brittle and is easily broken with the hammer. In the hand specimen it is a light-colored felsite with occasional phenocrysts of quartz and plagioclase visible with the aid of a hand lens. Small brownish areas suggest the presence

Figure 33. Photomicrograph of Columbia River basalt. Note ophitic texture. Plain light, x25.

Figure 34. Outcrop of leuco-dacite porphyry on top of Tony Butte. Note jointed appearance of outcrop.

of altered mafic constituents. The freshly broken rock is white (N9) to yellowish gray (5Y 7/2) but on the outcrop the color varies from light brown (5YR 5/6) to grayish brown (5YR 3/2).

Microscopically the rock has a porphyritic texture with embayed phenocrysts of zoned plagioclase feldspar and of quartz resting in a holocrystalline groundmass composed of oligoclase microlites, small grains of quartz, and shreds of biotite (Fig. 35). An average mode of three sections examined is given in Table 10 under (1).

The index of refraction of the plagioclase in the groundmass is between 1.542 and 1.546; the outer zones of the phenocrysts have about the same index and the inner zones are presumably more basic. These values indicate that the groundmass is oligoclase with a composition near Ab_8An_2 whereas the phenocrysts are oligoclase near the borders and probably andesine in the core.

Quartz is in the form of clear embayed phenocrysts and of small anhedral to subhedral crystals in the groundmass.

Accessory minerals include shreds of brown pleochloric biotite and wisp-like aggregates of magnetite.

Alteration products are green chlorite and limonite.

The order of crystallization appears to be: biotite, oligoclase, magnetite, quartz.

(2) Dacite porphyry. Small plugs of dark-colored dacite porphyry occur along the northwestern limb of the Mitchell anticline near the contact of the shale and conglomerate in Sections 4, 8 and 9, T. 11 S., R. 22 E. The plugs are circular or elliptical in

Table 10

Modes of Tertiary Dacitic Intrusive Rocks

Mineral	(1)*	(2)*	(3)	(4)	(5)	(6)	(7)
	Percentages						
Andesine	-	58	-	47	62	-	58
Oligoclase	65	-	59	-	-	-	-
Hornblende	-	T**	T	-	-	-	-
Biotite	2	5	4	-	-	-	-
Quartz	30	12	35	30	28	5	30
Glass	-	-	-	20	-	89	-
Magnetite	1	5	1	1	3	4	-
Apatite	-	T	T	-	-	-	-
Tourmaline	-	-	1	-	-	-	-
Chlorite	2	10	1	T	3	2	2
Limonite	T	T	T	-	2	T	-
Hematite	-	-	-	2	-	T	-
"Sericite"	T	T	T	T	T	T	T
Calcite	-	12	T	T	2	-	10

* Average of 3 slides examined.

** Trace; present in amounts less than 1%.

outline. The largest has a diameter of about 400 feet.

On the outcrop the most conspicuous feature of these plugs is the character of the jointing. The principal joints are vertical or nearly so and are spaced from two to three feet apart. These are intersected by another set, also vertical, at angles ranging from 60° to 90°. A third set, usually horizontal, intersects the other two joint sets so as to cause the rock to weather out in blocks which form talus deposits at the base of the plugs (Fig. 36).

The rock is dark yellowish brown (10YR 4/2) or moderate brown (5YR 4/4) on the weathered surface and dark greenish gray (5GY 4/1) on the fresh fracture. Plagioclase feldspar and an occasional quartz xenocryst are visible with the aid of the hand lens. The rock breaks with a conchoidal fracture and in the hand specimen resembles a basalt or andesite.

Under the microscope the dacitic nature of the rock is evident. The texture is porphyritic with a pilotaxitic groundmass. Corroded andesine phenocrysts rest in a fine-grained holocrystalline groundmass composed of andesine microlites, anhedral quartz, shreds of biotite, and partially resorbed hornblende crystals. All sections examined show extreme alteration and are unusually high in secondary calcite and chlorite. The average mode of three specimens examined is given in Table 10 under (2).

The maximum index of refraction of the plagioclase is less than 1.554 and the maximum extinction angle taken from the albite twinning is about 25°. These values place the plagioclase in the

Figure 35. Photomicrograph of leuco-dacite porphyry from Tony Butte. Note plagioclase phenocryst resting in groundmass composed of plagioclase laths and small crystals of quartz. Shreds of biotite appear along margin of phenocryst.

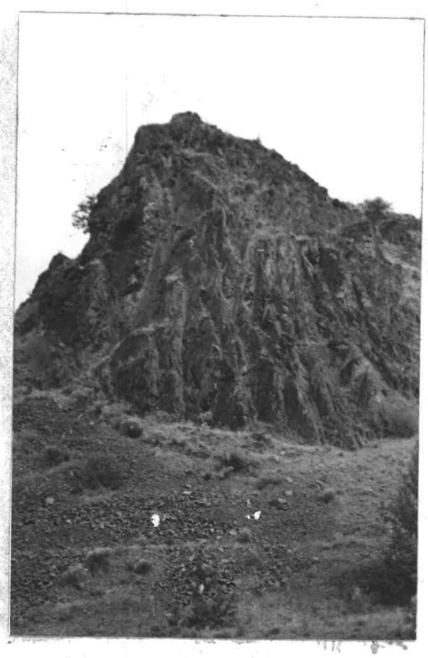


Figure 36. Small plug of dacite porphyry exposed along the Service Creek road.

andesine range with a composition near Ab_6An_4.

Quartz occurs as an interstitial filling. Some of the quartz may be secondary from the alteration of the plagioclase. An angular quartz xenocryst was observed in one section and small veinlets of secondary quartz are not uncommon.

Biotite is in the form of small subhedral embayed lath-like crystals. It is green in color and pleochloric in green and yellowish brown. Much of it is resorbed and surrounded by a rim of magnetite. Hornblende is rare, as occasional small pleochloric remnants.

Magnetite and apatite are the chief accessory minerals, and part of the magnetic is deuteric.

The rock has had a complex cooling history. Late magmatic reaction between the residual fluids in the magma and the earlier formed crystals has resulted in the resorption of much of the original mafic material and part of the plagioclase. The magma probably picked up considerable foreign material in its passage through the shales and sandstones. This conclusion is based in part on the quartz xenocryst previously mentioned.

(3) Tourmaline-bearing dacite porphyry. This unusual type occurs as two small irregular plugs in Sec. 33, T. 10 S., R. 22 E.

On the outcrop the rock is light brown (5YR 5/6) and on the fresh fracture light gray (N7). It is fresh in appearance and is hard under the hammer. It has a porphyritic texture with phenocrysts of quartz, biotite, and plagioclase resting in an aphanitic groundmass. Small reddish crystals of tourmaline are visible with the aid of a hand lens.

The microscope reveals a porphyritic holocrystalline texture with embayed and corroded phenocrysts of plagioclase feldspar, quartz and biotite resting in a very fine-grained groundmass of quartz, plagioclase and shreds of biotite.

Tourmaline occurs as small radiating aggregates of prismatic crystals, commonly between two phenocrysts of quartz (Fig. 37). The needles sometimes extend into the quartz and appear to have crystallized at a late stage. The tourmaline is pleochloric in bluish green and very pale blue. The presence of this mineral suggest that the "mineralizers" in the magma failed to escape before consolidation of the rock. A mode appears in Table 10 under (3).

(4) Fine-grained dacite, type 1. This rock occurs as plugs at Sand Mountain, at Sargent Butte, and northwest of Sargent Butte. The total areal extent of the three plugs is about 0.75 square mile.

The dacite is quite uniform in appearance at the three plugs. The best outcrops appear near the top of Sargent Butte where the dacite is massive in appearance and shows columnar jointing. Here the columns are vertical, rudely hexagonal in shape, and 4 to 10 inches in diameter. The slopes of the plugs are covered by angular blocks of the rock which form extensive talus deposits, obscuring the contact with the country rock (Fig. 38).

In the hand specimen the rock is distinguishable only as a

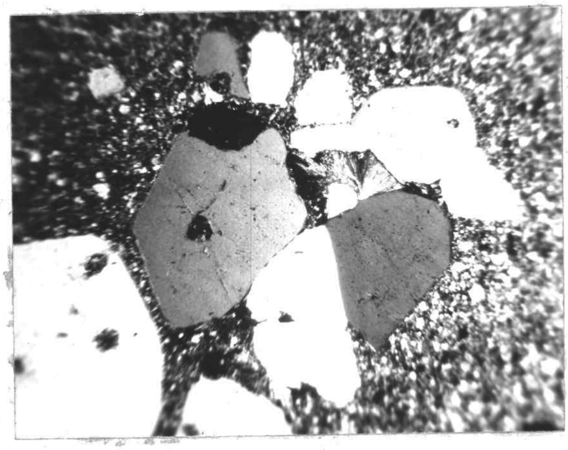


Figure 37. Photomicrograph of tourmaline-bearing dacite porphyry. Note quartz phenocrysts resting in a fine-grained groundmass composed of quartz and plagioclase. Tourmaline crystals appear between the quartz phenocrysts. Crossed nicols, x25.

Figure 38. Photograph showing the south slope of Sargent Butte. Note the extensive talus deposit.

light-colored felsite. On a fresh surface the rock is white (N9), while on the outcrop its color varies from light brown (5YR 5/6) to grayish orange pink (5YR 7/2).

Under the microscope the rock shows a microcrystalline to hypocrystalline texture with most constituents too minute for identification. Considerable light-colored glass is present and much of it is devitrified. Small, poorly developed spherulites composed of radial aggregates of plagioclase feldspar and rod-like grains of quartz occur. Irregular myrmekitic intergrowths of plagioclase and quartz are common (Fig. 39). The mode of a specimen from Sargent Butte is given in Table 10 under (4).

Its plagioclase has an index of refraction of about 1.55, placing it in the andesine-oligoclase range. The occurrence of myrmekitic intergrowths suggests that crystallization of plagioclase and quartz was simultaneous or nearly so.

Mafic minerals are conspicuously absent. Some shreds may be present, but if so they cannot be resolved.

Magnetite is present in stringy aggregrates and is more or less oxidized to light red hematite which stains the surrounding minerals.

(5) Fine-grained dacite and hyalo-dacite, type 2. This light colored felsite occurs as plugs and dikes northeast and southwest of Meyers Canyon (Fig. 40, 41). The plugs vary greatly in size and shape, the largest exposures occurring near the head of Meyers Canyon.

These rocks have an irregular closely spaced joint pattern

Figure 39. Photomicrograph of fine-grained dacite. Note the myrmekitic intergrowth of plagioclase and quartz. Crossed nicols, x25.

Figure 40. Contact between a dacite plug and the Frizzell conglomerate.

which gives the outcrop a characteristic hackly appearance. The rock is platy near its contact with the country rock.

Under the microscope the texture is hyaline or microcrystalline. Microcrystalline rocks are composed of minute crystals of quartz and plagioclase. These grade into glassy rocks containing 89 per cent light colored partially devitrified glass. Mafic constituents have been altered to chlorite. Limonite and hematite stain the rock and have been derived from late magnetite. Modes of three of these rocks are given in Table 10 under (5), (6), and (7).

Relations and Age. The age of the dacitic intrusives is not definitely known. They cut the Tony Butte meta-sediments, the Mitchell beds, and the Clarno formation. None of the dacitic or other intrusives were observed cutting formations younger than the Clarno formation in this area or in the Mitchell area as a whole.

At Meyers Canyon a dacitic plug has been cut by an andesitic dike and the dacitic plug at Tony Butte has been cut by a smaller basaltic plug indicating that these dacitic rocks are older than the andesitic and basaltic intrusives.

Therefore, the dacitic intrusive rocks are thought to be the oldest of the Tertiary intrusive rocks and are considered to be late Clarno or post-Clarno, pre-John Day in age on the basis of their relationship with the country rock.

3. Andesitic Intrusives

Distribution and Topographic Expression. Andesitic intrusives including plugs, dikes, and sill-like bodies occur in the south-central part of the area near the axis of the Mitchell anticline in Sections 8, 17 and 18, T. 11 S., R. 22 E.; along Limekiln Creek in Sec. 1, T. 11 S., R. 22 E.; in Sec. 13, T. 11 S., R. 22 E.; in a northeasterly trending belt southwest and northeast of Hill 3732; in Sec. 1, T. 11 S., R. 22 E.; and northeast of Hill 4308 in Sec. 5, T. 11 S., R. 22 E.

Topographically the plugs stand as resistant knobs above the country rock, while the dikes show little relief. Sill-like bodies in the south-central sector dip moderately, with the tops forming dip slopes toward the southeast.

Petrography. Andesitic intrusives are considered in the following order: (1) hornblende andesite porphyry and quartz-bearing hornblende andesite porphyry, (2) quartz-bearing augite andesite porphyry, (3) hornblende andesite and quartz-bearing hornblende andesite.

(1) Hornblende andesite porphyry and quartz-bearing hornblende andesite porphyry. The largest exposure of these rocks occurs in the south-central portion of the area, where plugs, dikes and sill-like bodies are exposed for a distance of about 2.3 miles near the axis of the Mitchell anticline. Plugs 800 feet in diameter occur, with dikes commonly 2 to 80 feet wide and as much as 1000 feet long.

Along Limekiln Creek a plug about 800 feet wide and 3100 feet long is exposed, while a plug nearly 800 feet in diameter is exposed in Sec. 13, T. 11 S., R. 22 E.

The andesites commonly show columnar jointing with individual columns ranging in diameter from 3 to 10 inches. The columns are generally hexagonal; they are vertical or nearly so in the plugs, nearly horizontal in the dikes, and inclined in the sill-like bodies.

On the outcrop the rock is moderate yellowish brown (10Y 5/2) and on the fresh fracture pale olive (10Y 6/2) to yellowish gray (5X 7/2). In the hand specimen the rock has a porphyritic texture with needles of greenish black hornblende and white phenocrysts of plagioclase imbedded in an aphanitic groundmass. Aligned hornblende needles attain a length of ½ inch and are the most characteristic feature of the rock.

The microscope reveals altered phenocrysts of hornblende and plagioclase resting in a fine-grained groundmass of plagioclase microlites, occasional shreds of biotite, and in some specimens interstitial quartz. Modes of these rocks are given in Table 12 under (8), (10), and (12). The location and classification of rocks appearing in Tables 10, 12, and 13 are given in Table 11.

Plagioclase occurs in two generations, as phenocrysts and as microlites. It is considerably altered to calcite and sericite. Most phenocrysts are twinned and many are zoned.

Hornblende, usually twinned, is yellowish green and pleochloric in light yellowish green and dark yellowish green. All hornblende phenocrysts show alteration, and most of the crystals have a core of unaltered material surrounded by a prominent reaction rim composed of magnetite (Fig. 42).

Table 11

Classification and Location of Rocks Appearing
in Tables 10, 12 and 13

No.	Rock Name	Occurrence	Sample No.	Location
(1)	Leuco-dacite porphyry	Plug	X-111	35/10S./22E.
(2)	Dacite porphyry	Plugs, dikes	X-301	9/11S./22E.
			X-303	4/11S./22E.
			X-304	8/11S./22E.
(3)	Tourmaline-bearing dacite porphyry	Plugs	X-136	33/10S./22E.
(4)	Fine-grained leuco-dacite	Plugs, dikes	X-232	16/11S./22E.
(5)	Fine-grained dacite	Plugs, dikes	101-X	
(6)	Hyalo-dacite	Plug	X-186	15/11S./22E.
(7)	Fine-grained dacite (contact rock)	Plug	X-96	9/11S./22E.
(8)	Quartz-bearing hornblende andesite porphyry	Plugs, dikes, sill-like bodies	X-102	16/11S./22E.
(9)	Andesite porphyry	Sill-like body	X-99	17/11S./22E.
(10)	Hornblende andesite porphyry	Plug	101-X	16/11S./22E.
(11)	Andesite porphyry	Dikes	42-X	12/11S./22E.
(12)	Hornblende andesite porphyry	Plug	X-84	13/11S./22E.
(13)	Quartz-bearing augite andesite	Plug	93-X	12/11S./21E.
(14)	Quartz-bearing hornblende andesite	Plug	X-202	12/11S./21E.
(15)	Hornblende andesite	Plug	X-188	15/11S./21E.
(16)	Quartz-bearing hornblende andesite	Plug	X-212	11/11S./21E.
(17)	Quartz-bearing andesite	Dikes	X-213	11/11S./21E.
(18)	Quartz-bearing andesite	Dikes	144-X	12/11S./21E.
(19)	Quartz-bearing hornblende andesite	Dike	27-X	2/11S./22E.
(20)	Quartz-bearing hypersthene basalt porphyry	Dikes	X-4	6/11S./22E.
			X-263	11/11S./21E.
			X-291	12/11S./21E.
(21)	Hypersthene basalt porphyry	Dike	X-260	18/11S./21E.
(22)	Hypersthene basalt porphyry	Dike	X-184	2/11S./21E.
(23)	Olivine basalt porphyry	Dikes,plug	X-174	33/10S./22E.
(24)	Hyaline basalt porphyry	Plug	X-168	35/10S./22E.

Table 12

Modes of Tertiary Andesitic Intrusive Rocks

Mineral	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	Percentages											
Andesine	67	83	11	76	76	71	63	55	66	74	70	59
Augite	-	-	-	-	-	15	-	-	-	-	-	-
Hornblende	20	T*	9	-	3	-	2	9	7	-	T	25
Biotite	2	-	-	-	2	-	-	-	-	-	-	-
Quartz	4	1	-	T	-	4	2	T	4	4	4	2
Magnetite	3	4	2	4	2	4	3	3	5	3	4	4
Pyrite	-	-	-	-	-	-	-	-	-	-	T	-
Apatite	T	T	-	T	T	-	-	-	T	T	-	T
Chlorite	3	10	15	10	15	5	20	25	6	4	8	7
Serpentine	-	-	-	-	-	-	2	-	-	-	-	-
Limonite	T	T	-	T	T	T	-	-	T	-	-	-
"Sericite"	1	1	T	T	T	T	T	T	T	T	T	T
Calcite	1	-	3	10	2	1	7	10	12	15	14	3

* Trace; present in amounts less than 1%.

Table 13

Modes of Tertiary Basaltic Intrusive Rocks

Mineral	(20)	(21)	(22)	(23)	(24)
	Percentages				
Labradorite	47	61	51	47	54
Augite	15	14	15	35	15
Hypersthene	8	8	8	-	-
Olivine	-	-	-	8	-
Quartz	3	-	-	-	-
Glass	21	5	21	-	31
Magnetite	5	10	5	5	3
Apatite	T*	T	T	T	-
Chlorite	T	1	T	2	T
Serpentine	-	-	-	2	-
Limonite	T	T	T	-	T
Hematite	T	1	T	-	T
Calcite	1	-	T	T	T
Iddingsite	-	-	-	1	-

* Trace; present in amounts less than 1%.

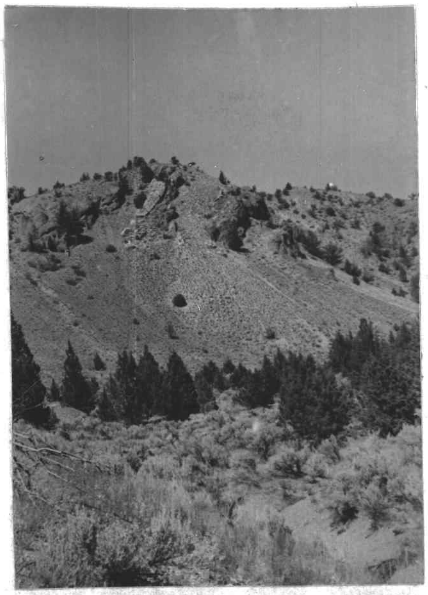


Figure 41. Dacite dike 10 feet in width cutting the Frizzell conglomerate.

Figure 42. Photomicrograph of hornblende andesite porphyry. Note rim of secondary magnetite surrounding hornblende phenocryst. Plain light, x25.

Quartz is present in the groundmass of many of the specimens examined, as small subhedral grains interstitial to the other minerals in the groundmass.

Biotite, apatite, and magnetite occur as accessory minerals and present no unusual features.

The order of crystallization appears to be: magnetite, apatite, hornblende, biotite, plagioclase, quartz.

(2) Quartz-bearing augite andesite. Only one exposure of this type was observed. It occurs as a small elliptical plug about 500 feet in diameter in Sec. 11, T. 11 S., R. 21 E.

On the outcrop the rock is dark yellowish brown (10YR 4/2) while on the fresh surface it is greenish gray (5GY 6/1). Small laths of plagioclase are seen in the hand specimen.

Under the microscope the rock has a very fine-grained texture ranging from pilitic to trachitic and is composed essentially of small laths of plagioclase and small crystals of augite with minor amounts of quartz, magnetite, and the alteration products chlorite, calcite, and sericite. The mode is given in Table 12 under (13).

(3) Hornblende andesite and quartz-bearing hornblende andesite. Hornblende andesites, some of them containing quartz, occur as plugs and dikes in a northeasterly trending belt southwest and northeast of Hill 3732 in Sections 11, 12, 13, 14 and 15, T. 11 S., R. 21 E. The rock also occurs as a dike southeast of Tony Butte and as a plug in Sec. 32, T. 10 S., R. 22 E.

Petrography. On the weathered surface the rock is brownish black (5YR 2/1) or grayish brown (5YR 3/2). On a fresh surface its color varies from greenish gray (5GY 6/1) to medium gray (N4). The rocks are very fine-grained and minute lath-like crystals of plagioclase are the only minerals visible in the hand specimen.

Microscopically the rocks have textures ranging from pilitic to pilotaxitic and are composed of plagioclase feldspar and small altered euhedral to anhedral crystals of hornblende. The rocks are considerably altered, and the hornblende is partially resorbed and has a rim of deuteric magnetite surrounding it. The resorption in some instances is complete so only "ghosts" of chlorite and magnetite mark their former presence. Modes of the rock are given in Table 12 under (14), (15), (16), (17), (18), and (19).

Relations and Age. The hornblende andesite porphyry and quartz-bearing hornblende andesite porphyry intrude the Tony Butte meta-sediments, the Mitchell beds, and the lower part of the Clarno formation. The plugs and dikes disrupt the country rock and where in contact with the Frizzell shale, bake and harden it for distances of three feet from the contact. Of the intrusives in the south-central sector some are of discordant and others apparently concordant. Two or possibly three sill-like bodies are present, varying in dip from 7° to 30°. The bottom contact of these intrusives is exposed at several localities along both the northwest and southeast margins (Fig. 43) and the top contact with the overlying shale is exposed in a small valley in the southeast part of Sec. 18, T. 11 S., R. 22 E.

Along both the top and bottom contacts the shale is baked and hardened. The bodies are considered sill-like, rather than definite sills, because dips and strikes of the shale country rock vary greatly, and the intrusives cannot be said definitely to be strictly conformable with the shale.

Andesite near the bottom contact with the shale is fine-grained as in chilled margins but at the top contact the andesite is coarse-grained and does not appear to have been chilled. No scoriaceous, vesicular, or amygdaloidal material which would suggest flows was observed. The rocks making up this intrusive mass are uniform in appearance and composition. Dikes are commonly finer-grained than the plugs and sill-like bodies. It appears likely that the emplacement of the various intrusives occurred at nearly the same time.

Quartz-bearing augite andesite cuts basalt of the Clarno formation.

Hornblende and quartz-bearing hornblende andesites intrude the Mitchell beds and the lower part of the Clarno formation. They intrude the Mitchell beds along a northeasterly trending strike fault. They also intrude the dacitic plug near the southern end of this fault.

The andesitic dike cutting the dacite at Meyers Canyon is younger than the dacite, and in general it is thought that the andesitic intrusives are younger than the dacites throughout the area.

On the basis of their spatial relationships with the country rocks the andesites are considered late Clarno or post-Clarno, pre-John Day in age.

4. Basaltic Intrusives

Distribution and Topographic Expression. The distribution of these rocks is rather scattered. Basaltic dikes occur in a semi-peripheral arrangement on the southern margin of Sand Mountain; at Hill 3507 in Sec. 2, T. 11 S., R. 21 E.; at scattered localities northeast and southwest of this hill; on the shale ridge 3/4 mile north of the head of Meyers Canyon; in the SW. $\frac{1}{4}$, Sec. 33, T. 10 S., R. 22 E.; and in the NW. $\frac{1}{4}$, Sec. 4, T. 11 S., R. 22 E.

Plugs of basalt occur in the NW. $\frac{1}{4}$ Sec. 4, T. 11 S., R. 22 E. and on the northwestern side of Tony Butte.

The dikes form resistant linear ridges and small scattered tits which stand in slight relief above the country rock.

Petrography. Basaltic intrusive rocks are considered in the following order: (1) quartz-bearing hypersthene basalt porphyry and hypersthene basalt porphyry, (2) olivine basalt porphyry, and (3) hyaline basalt porphyry.

(1) Quartz-bearing hypersthene basalt porphyry and hypersthene basalt porphyry. These rocks occur as dikes on the southern margin of Sand Mountain; in the vicinity of Hill 3507; and on a shale ridge in the SW. $\frac{1}{4}$ Sec. 12, T. 11 S., R. 21 E.

Near Sand Mountain the dikes are rather narrow, not exceeding 10 feet in width, and have a maximum exposed length of about 700 feet. At Hill 2507 is a large dike about 80 feet wide and 400 feet long. Northeast and southwest of this hill other smaller dikes are exposed.

These rocks are dark-colored hypersthene basalt porphyries. Quartz occurs as rounded to sub-angular embayed and corroded fragments in some of the rocks.

At Hill 3507, the dike dips about 70° to the southeast and has well developed columnar jointing (Fig. 44). Columns are hexagonal in outline, about 10 inches in diameter, and are normal to the margins of the dike. The other dikes are not well exposed and their outcrops are reduced to a jumble of angular blocks. The rock breaks with a conchoidal fracture and is brittle under a hammer blow. On the outcrop the rock is dark yellowish brown (10YR 4/2) to grayish brown (5YR 3/2), while on the fresh fracture it is grayish black (N2). Close inspection of the rock with a hand lens reveals small phenocrysts of plagioclase feldspar and an occasional quartz fragment surrounded by a reaction rim. The groundmass is very fine-grained and glassy in appearance.

The microscope reveals a porphyritic texture with phenocrysts of labradorite, hypersthene, and augite, and an occasional grain of embayed and corroded quartz, resting in a hyalopilitic groundmass of plagioclase feldspar, glass, and small crystals of augite.

An average mode of three quartz-bearing basalts is given in Table 13 under (20) and the modes of two basalts not containing quartz are given in the same table under (21) and (22).

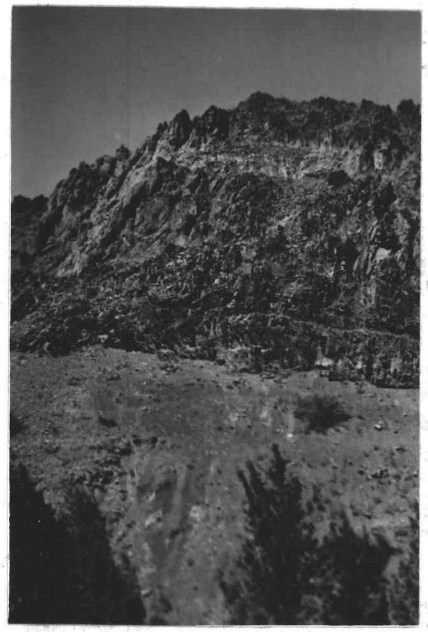


Figure 43. Contact of Frizzell shale and a sill-like body of hornblende andesite.

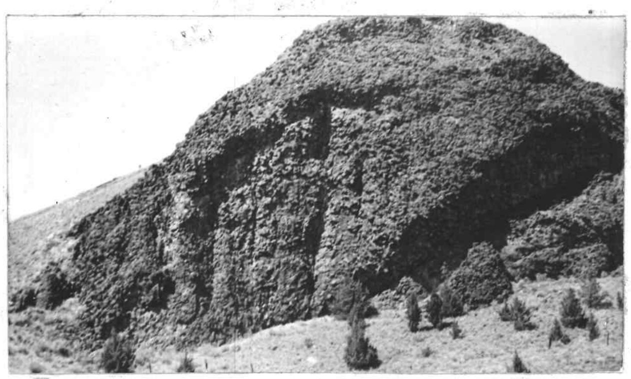


Figure 44. Exposure of a hypersthene basalt dike at Hill 4307. Dike cuts the Clarno formation.

Labradorite occurs in two generations as euhedral to subhedral phenocrysts and as microlites in the groundmass. A majority of the phenocrysts show well developed albite twinning with a maximum observed extinction angle of 40°. The index of refraction of these phenocrysts lies between 1.564 and 1.566, indicating a composition of about Ab_4An_6.

Some of the plagioclase phenocrysts have well developed zoning caused by differences in the composition of the several layers making up the crystal. Most feldspar phenocrysts are rather irregular in outline and embayed, and contain inclusions of brown glass and occasional small crystals of augite. Glass inclusions contain minute crystallites and small euhedral microlites of plagioclase. A narrow zone extending completely around the margin of the phenocrysts is clear and free of any inclusions. The core of the plagioclase contains narrow intersecting bands of a dark-colored unidentified substance which divides the crystal into small prismatic or elongate areas (Fig. 45).

The plagioclase in the groundmass is in the form of small unoriented lath-like microlites which rest in a base of brown glass.

Augite is present in two generations. It occurs as subhedral embayed phenocrysts and as small crystals in the groundmass. Phenocrysts are pale green and have a birefrigence of about 0.024. The augite has a small 2E characteristic of a pigeonitic variety. Its phenocrysts contain small inclusions of brown glass, magnetite, and some unidentified minerals. In the groundmass the augite crystals have a random orientation.

Hypersthene occurs as subhedral embayed phenocrysts (Fig. 46) pleochloric in light green and pink. Phenocrysts are surrounded by brownish glass in which small crystals of augite occur. Augite crystals are oriented with their long, or C, axis normal to the hypersthene crystal. Phenocrysts of hypersthene and augite commonly occur together in clusters.

Magnetite occurs as small euhedral to subhedral crystals in the groundmass, as inclusions in the hypersthene, augite and labradorite phenocrysts, and as dust in the glass. Magnetite swarms may mark the former presence of resorbed mafic constituents.

Brown glass, containing numerous crystallites in the form of margarites and globulites, is estimated to make up 20 per cent of the rock. Glass occurs mainly in the groundmass as an interstitial filling but also occurs as inclusions in the phenocrysts.

Probably the most interesting feature is the occurrence of quartz in some of the rocks. It is present as small rounded to angular somewhat resorbed fragments distributed fairly evenly throughout the rock. Quartz is clear and somewhat fractured, and occasionally contains inclusions of an unidentified dark-colored amorphous substance. Some quartz grains, identical in appearance, show a typical uniaxial figure. Winchell (34, p. 247) notes that quartz may show a 2V as high as 24°.

The quartz has been embayed, corroded, and rounded by late magmatic solutions. It is typically surrounded by brown glass

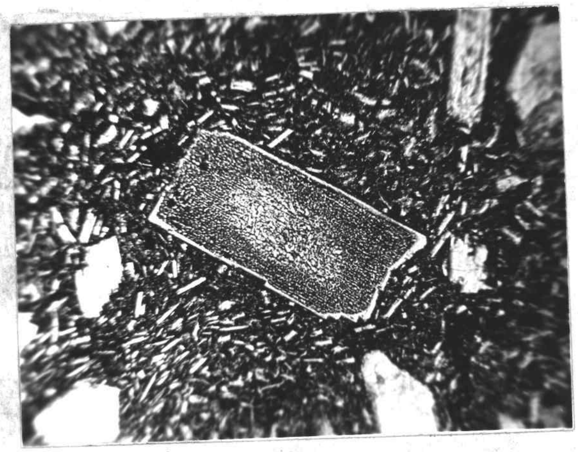


Figure 45. Photomicrograph of a labradotite phenocryst in a quartz-bearing hypersthene basalt. Note the clear marginal zone surrounding a core containing numerous unidentified inclusions. Plain light, x25.

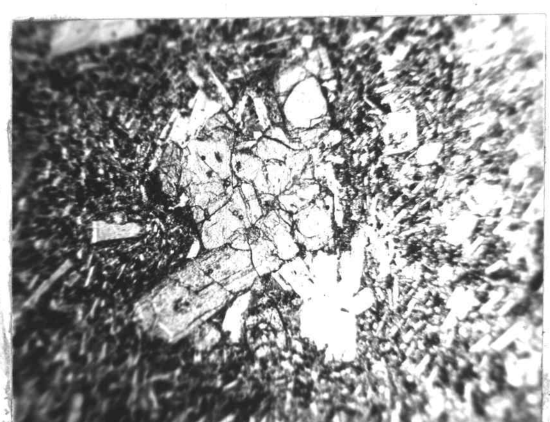


Figure 46. Photomicrograph of hypersthene crystals in a quartz-bearing hypersthene basalt. Crossed nicols, x25.

containing crystallites and numerous small prismatic crystals of augite. Most of the augite crystals are oriented with their C-axes normal to the edge of the quartz fragment. Surrounding the augite crystals are zones containing limonite, hematite, occasionally calcite, and brown glass containing dust-like particles of magnetite (Fig. 47, 48). All gradations from complete resorption of the quartz to little resorption occur. Fragments which have been completely resorbed show a nest of augite crystals surrounded by a rim of limonite, hematite, and glass. Rims are much less conspicuous around the more angular fragments.

Similar rims have been observed and recorded by several petrographers who have studied quartz basalts and quartz-bearing basalts. Diller (9, p. 25), describing a quartz basalt from the Lassen Peak district of California noted and described this effect. He states, in part:

> "Each grain of quartz...is encircled by a shell of granular, acicular augite which is separated from the quartz by a film of glass. The borders of the glass and augite are constant features of the quartz and appear to be reactionary rims resulting from the corrosion of the quartz by the magma."

In referring to a plate which shows drawings of the phenomena, Diller continues:

> "In No. 5 the quartz has entirely disappeared, and in No. 6 the glass has gone also leaving a group of augite crystals to tell the story. In this way structures are produced which appear in most cases at least to be identical with the so called 'augite eyes' (augitaugen) which are well known in a number of European basalts....The pyroxene of the border may be crystallized or granular. Rather long thin crystals are most numerous and frequently converge, penetrating

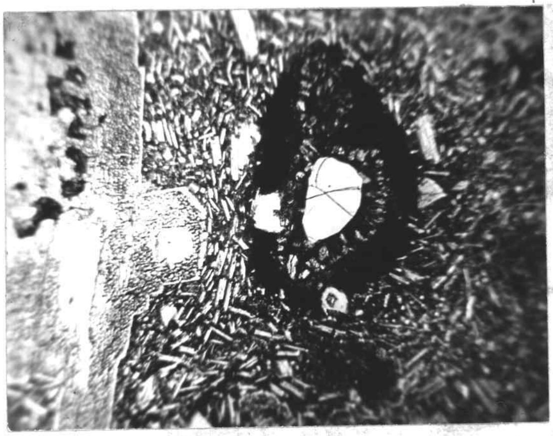


Figure 47. Photomicrograph showing a rounded quartz inclusion in a quartz-bearing hypersthene basalt. Note the reaction rim surrounding the quartz, composed of augite crystals, glass, and magnetite. Plain light, x25.

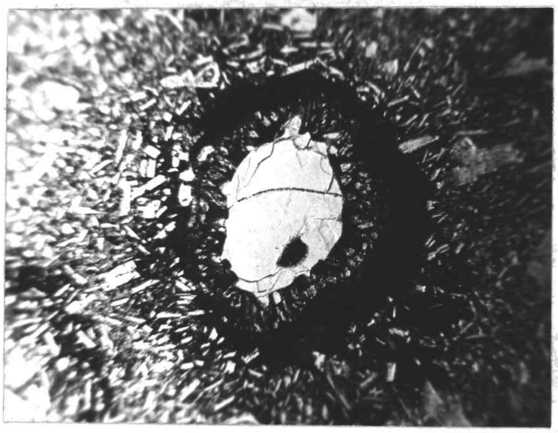


Figure 48. Photomicrograph of a quartz inclusion in a quartz-bearing hypersthene basalt. Plain light, x25.

> the glass toward the disappearing quartz in such a way as to indicate the direction of their growth."

Calkins (2, p. 135) described a quartz-bearing hypersthene basalt from Cherry Creek, Oregon. He states:

> "Each grain of quartz is surrounded by a zone of brown glass, bordered in turn by a wreath of small prisms of pale green augite. The degree of resorption presents all gradations, and there has often resulted the complete destruction of the quartz, whose place is then marked by a nest of augite prisms."

Iddings (13, p. 20-32) presents a detailed description of the phenomena. Johannsen (14, p. 414) notes the effect and presents additional references.

Waters et al. (32, p. 114) noted the occurrence of quartz in some of the Clarno andesites in the Horse Heaven district. The quartz in these rocks was considered to be inclusions derived from older rocks.

The quartz in the basalt under discussion was probably picked up by the magma on its way to the surface. Evidence supporting this view is seen in the angular nature of some of the quartz grains and in the associated resorption effects. Rounded fragments show much resorption while the more angular fragments show little. The quartz content of the rocks varies from place to place, and the quartz-bearing rocks appear on either side of a quartz-free portion of presumably the same dike. This spotty occurrence is well illustrated in the vicinity of Hill 3507.

(2) Olivine basalt porphyry. Dikes and a small plug of this rock occur in the SW. $\frac{1}{4}$ Sec. 33, T. 10 S., R. 22 E. and in the NW. $\frac{1}{4}$

Sec. 4, T. 11 S., R. 22 E. Dikes are 2 to 4 feet wide, 200 to 400 feet long, and strike N. 30° E. (Fig. 49). The plug is poorly exposed but is estimated to have a diameter of about 200 feet.

In Sec. 34, T. 10 S., R. 21 E., outcrops of an olivine basalt dike 20 to 30 feet wide is exposed on the crest of an easterly trending ridge.

On the outcrop the dikes exhibit crude columnar jointing perpendicular to the contact with the country rock. In Sec. 4, T. 11 S., R. 22 E., several small parallel dikes are separated by a screen of shale only a few inches thick. The shale adjacent to the contact with the basalt is baked and hardened.

With the aid of a hand lens the only minerals recognizable are small laths of plagioclase and minute yellowish green grains of olivine. On the fresh fracture the color of the rock is grayish black (N2), while on the weathered surface it varies from light brown (5YR 5/6) to moderate brown (5YR 4/4). The rock breaks with a conchoidal fracture and on the broken surface is fresh in appearance.

Under the microscope the rock shows a porphyritic texture. Phenocrysts of rounded olivine (Fig. 50) rest in a groundmass made up of labradorite microlites, small subhedral crystals of augite, subhedral crystals of magnetite, and occasional small crystals of olivine.

The order of crystallization appears to be magnetite and apatite, olivine, augite, labradorite.

A mode of the rock appears in Table 13 under (23).

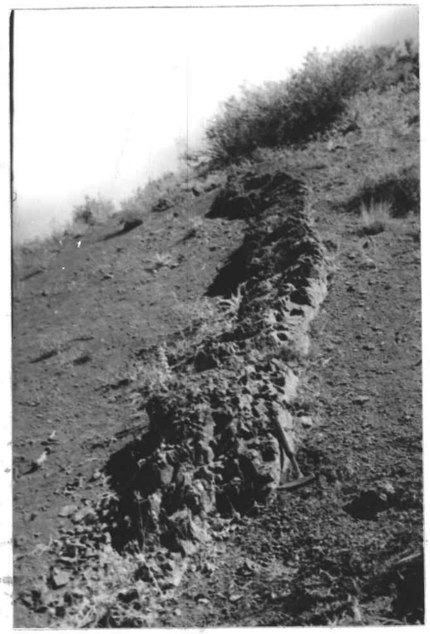


Figure 49. Olivine basalt dike cutting the Frizzell conglomerate unit.

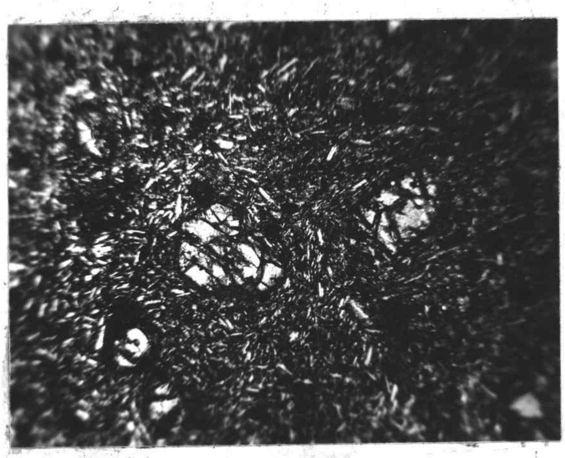


Figure 50. Photomicrograph of olivine basalt porphyry from dike shown in above figure. Note the altered appearance of the olivine phenocrysts. Plain light, x.25.

(3) Hyaline basalt porphyry. This basalt occurs as a small plug about 200 feet in diameter on the northeastern side of Tony Butte.

Near the core of the plug, crude hexagonal columnar jointing is evident with the columns vertical or nearly so. On the outcrop the rock is brownish gray (5YR 4/1) while on the fresh fracture it is grayish black (N2) or black (N1). Small phenocrysts of plagioclase are visible with the hand lens and the rock has a glassy appearance.

Under the microscope the texture is seen to be porphyritic with small phenocrysts of corroded and embayed labradorite and augite, and yellow and brown partially devitrified glass. The order of crystallization appears to be magnetite, augite, labradorite, glass. A mode is given in Table 13 under (24).

Relations and Age. Hypersthene basalt porphyry and quartz-bearing hypersthene basalt porphyry intrude the Mitchell beds and the Clarno formation. Hyaline basalt porphyry which occurs on the northeast side of Tony Butte cuts the leuco-dacite porphyry. Therefore, these basalts are considered later than the dacitic intrusives and hence probably late Clarno or post-Clarno, pre-John Day in age.

Olivine basalt porphyry cuts the Mitchell beds and the Clarno formation and has a composition similar to the Middle Miocene Columbia River basalt. Dikes cannot be traced into these basalts but it is thought that they represent feeder dikes of these flows, which would place them in the Middle Miocene.

Olivine was not noted in any of the extrusive rocks of the

Clarno formation and this fact supports the Middle Miocene age reference.

STRUCTURE

General Features

Structural features within the area include folds, faults, and intrusives in the form of plugs, dikes and sill-like bodies. With the exception of the meta-sediments the rocks have a general northeasterly trend and the larger faults, and many of the intrusive bodies, conform to this trend.

The principal structural feature is the Mitchell anticline, a generally symmetrical fold which trends northeasterly through the area. The northwestern limb of this structure forms the southeast limb of a northeasterly plunging syncline. The axis of this syncline lies to the north of the area. The anticline plunges to the northeast in the vicinity of Tony Butte and the Mitchell beds exposed along the axis plunge beneath Tertiary rocks in the vicinity of the Waldron School, about two miles north of Tony Butte.

The anticlinal nature of the fold has been disrupted and somewhat obscured by Tertiary strike faulting on the northwest limb and by the emplacement of numerous intrusives of Tertiary age.

Structures Referable to Pre-Tertiary Deformation

The oldest rocks in the area, the Tony Butte meta-sediments, are structurally complex and have undergone several periods of deformation. They were closely folded, fractured, and metamorphosed prior to the deposition of the Mitchell beds. Evidence of this pre-Upper Cretaceous deformation is well displayed at Tony Butte and at Meyers Canyon where the meta-sediments lie with a distinct angular unconformity beneath the younger Mitchell beds. The meta-sediments are vertical or have high dips; are silicified and fractured; contain small drag folds; and contain phyllites which show a pronounced schistosity apparently parallel to the bedding.

The rocks underwent regional metamorphism prior to the deposition of the Mitchell beds, as proved by the relatively unmetamorphosed character of the overlying marine sediments. It appears that the metamorphism was of relatively low grade, perhaps corresponding to the green schist facies as defined by Turner and Verhoogen (29, p. 465).

Following the deformation, uplift, and erosion of the meta-sediments, a sea transgressed over the area and a subsiding basin of deposition was developed on the old erosion surface, which received sediments from adjacent uplifted areas.

There is structural evidence that these accumulated sediments, the Mitchell beds, were folded, fractured, and eroded prior to the initial vulcanism which marked the beginning of the Eocene Epoch. On both limbs of the Mitchell anticline there is an angular unconformity between the Mitchell beds and the overlying Clarno formation. This angular discordance varies from 7° to 20°. Further evidence of deformation and erosion is the occurrence of Clarno volcanics resting unconformably upon all three units of the Mitchell beds and upon the meta-sediments as well. Therefore, the Mitchell beds and the older rocks were folded prior to the Eocene Epoch into a broad northeasterly trending anticlinal structure by compressive forces operating from the southeast and the northwest. A westerly trending fault probably of pre-Tertiary age occurs west of Hill 5118 in Sec. 11, T. 11 S., R. 22 E. The northern block is relatively up-thrown but the amount of displacement is not known.

Structures Referable to Tertiary Deformation

1. Pre-Miocene Deformation

Compressive forces again became active after the accumulation of the Clarno formation, resulting in closer folding of the Mitchell beds. Most of the faulting in the area and the emplacement of most of the intrusive masses probably also occurred after the accumulation of the Clarno formation.

An angular unconformity between the Clarno formation and the overlying John Day beds, varying from 6 to 16°, attests to post-Clarno, pre-John Day folding.

Most of the faulting of the Mitchell beds probably occurred near the close of the Eocene Epoch. Direct evidence for this statement is lacking but some of the faults appear to be connected with the emplacement of dacitic intrusives of probable Eocene or post-Eocene, pre-John Day age.

On the northwest limb of the Mitchell anticline a series of northeasterly trending strike faults have tilted and disrupted the Mitchell beds. The western-most fault is traceable from the dacitic intrusive at Meyers Canyon nearly to Hill 4308 in Sec. 6, T. 11 S., R. 22 E. Its gouge and breccia zone is 40 feet wide and the conglomerate on the western down-thrown block shows some slickensides. The trace of the fault plane crosses the valleys and ridges in a straight line, so as to indicate that the fault plane is vertical or nearly so. Andesitic dikes 20 feet wide occur along this fault and along a branch fault to the northwest. The vertical displacement along the fault is not known.

Southeast of this fault a series of five strike faults was observed, all having the southeastern side relatively up-thrown (Fig. 51). The apparent vertical displacement on these faults varies from about 150 to 300 feet. These faults are well exposed along the southwestern edge of the ridge in Sec. 7, T. 11 S., R. 22 E., but in the conglomerate to the northeast they are mostly inferred from fault line scarps in the vicinity of Hill 4308. They are not traceable in the shale to the southwest because of soil cover and vegetation.

At Hill 4300, in Sec. 33, T. 10 S., R. 22 E., a fault, which may be a continuation of the fault beginning at Meyers Canyon, also trends northeast and displaces the Clarno tuffs and the overlying basalts. The apparent vertical displacement is about 130 feet; the eastern side is relatively up-thrown. This fault cannot be traced into the shales to the southeast because of alluvium and vegetation. A dacitic intrusive along the western edge of the fault may

Figure 51. Fault contact between the Frizzell conglomerate and Frizzell shale exposed on west side of Service Creek road. Note gouge zone in small valley on right side of photograph.

have caused the fracturing.

West of Sargent Butte an easterly trending fault appears to run into the dacitic plug. The northern side has been up-thrown and Cretaceous conglomerate is exposed in fault contact with basalts of the Clarno formation. The vertical displacement is not known. Criteria for this fault include fault breccia and repetition of beds.

An inferred high angle reverse fault, probably associated with the emplacement of the plug at Tony Butte, occurs on the western edge of the butte. Here the Basal Mitchell beds are thought to be in fault contact with conglomerates of the Frizzell conglomerate unit. The only criterion for this fault is the abrupt change in dip on opposite sides of it, as the conglomerates in the Basal unit and those in the Frizzell conglomerate unit are not distinctive in the field. The vertical displacement is not known.

Other faults are present in the southeastern part of the area. Two of these are on the eastern side of Limekiln Creek where basalts of the Clarno formation are in fault contact with the Tony Butte meta-sediments and the Basal Mitchell unit. The vertical displacement is not known but is probably small, as the faults are traceable for only a short distance.

In Sec. 14, T. 11 S., R. 22 E., a northerly trending fault offsets the Frizzell conglomerate unit and the volcanic breccia of the Clarno formation. The vertical displacement is about 400 feet; the eastern side is up-thrown.

The intrusion of the plugs and dikes has resulted in considerable deformation. Around Tony Butte and at Meyers Canyon dacitic plugs have shouldered aside and turned up the surrounding country rock, so as to obscure the pre-intrusive structure. At Tony Butte and Meyers Canyon the old rocks appear to have been dragged up on the margins of the plugs, resulting in locally high dips and variable strikes.

Around the smaller plugs and dikes the country rock has been deranged and so dips and strikes are highly variable. At Sand Mountain and at Sargent Butte the effect on the country rock is obscured by talus, soil, and vegetation.

2. Post-Miocene Deformation

Following the accumulation of the John Day tuffs and extrusion of the Columbia River basalt, deformation again occurred. The compressional forces again were from the southeast and the northwest and resulted in the folding of the Columbia River basalt, the John Day formation, and the underlying beds. The Columbia River basalt on Sutton Mountain and the underlying John Day tuffs clearly show the effects of this folding. They dip to the north and northeast and form the southeast limb of a northeasterly plunging syncline.

Deformation which occurred at the close of the Miocene is the last evidence of major disturbance in the area. It is probable that Pliocene deformation also occurred but no evidence was observed in the area.

PHYSIOGRAPHY

The area is located within the physiographic province known as the Columbia River Plateau in which the dominant physiographic control is exerted by the Columbia River Basalt formation. In this local area folding and subsequent erosion have exposed older rocks and so the physiographic control exerted by the Columbia River basalt is restricted to the Sutton Mountain tract.

The present physiographic features within the area are mainly the result of the differential erosion of the components of the northeasterly trending Mitchell anticline. Along the axis of this fold, Cretaceous shales with interbedded sandstones form valleys or topographic lows, while on the flanks of the structure the overlying Cretaceous conglomerate and Clarno volcanics have been etched into resistant ridges standing in marked relief above the weaker shales.

The John Day formation, which overlies the Clarno volcanics, is relatively weak and forms typical badland features. The Columbia River basalts overlying it form a steep escarpment which rises above the underlying John Day tuffs, and the uppermost flows form dip slopes to the north and northeast.

At the present time the area is relatively well dissected to a stage of late youth or early maturity in the erosional cycle.

During the Quaternary, streams flowing south from Sutton Mountain towards Bridge Creek over the John Day formation developed a surface upon the John Day sloping about 5° towards Bridge Creek.

An alluvial fan or fans consisting of basaltic detritus from Sutton Mountain was deposited upon this surface. Later it was dissected, but remnants of the fan were left upon the ridge tops.

In the Bridge Creek Valley, east of Sargent Butte, rounded pebbles and cobbles of various types including metamorphic rocks occur as small remnants of terraces at least 50 feet above the present level of Bridge Creek.

The origin of these and similar terraces in Meyers Canyon is not known, but at least two explanations are possible.

Recent uplift, with consequent rejuvenation of the streams is one possibility, although uplift cannot be proved.

It was noted that at the junction of Meyers Creek and Bridge Creek, resistant basalts of the Clarno formation have been cut through by both streams, and that the terraces occur only upstream from this point. This relation suggests that the deposits may have been formed when the streams down-cutting ability was temporarily halted by the resistant nature of the basalt flows. When the streams managed to cut through the obstacle, remnants of the valley alluvium were left at a high level to form terraces.

An analogous setting in line with this inference may be seen near the mouth of Meyers Canyon today, where a waterfall about 30 feet high caused by a resistant Clarno basalt flow has given Meyers Creek a temporary base level. Meyers Creek cannot deepen its channel above this site until the stream cuts through the resistant flow but it can widen its channel and destroy the terraces. About

1200 feet south of the waterfall site the junction of the stream with Bridge Creek is accordant.

Of the two possibilities presented to account for the terraces, the latter inference appears to be the most probable.

Differential erosion of plugs has resulted in the formation of several volcanic buttes, such as Tony Butte, Sargent Butte, and Sand Mountain.

Other physiographic features include fault line scarps and tilted and eroded fault blocks on the northwest limb of the Mitchell anticline northwest of Meyers Canyon.

ECONOMIC GEOLOGY

Economic interest in the area has been confined largely to limited exploration for petroleum in the Mitchell beds, and to the possible utilization of limestone occurring in the meta-sediments. There have been several small efforts to discover metallic mineral deposits. Unfortunately, none of these ventures has proved successful.

In the spring of 1951 a dry hole was drilled by a private company in the NW. $\frac{1}{4}$ Sec. 18, T. 11 S., R. 22 E. The hole passed through the Frizzell shale and the Basal unit and encountered metamorphic rocks at a depth of about 820 feet. Drilling continued to a depth of 1415 feet in the metamorphics and was discontinued.

Along Limekiln Creek, limestone has been used locally by ranchers as an ingredient in sheep-dip. Moore (20, p. 148) and

Collier (7, p. 39,41) have investigated the limestone and both wrote rather unfavorable reports, because of the small tonnages present and the remoteness of the deposits from potential markets.

The metasediments contain small veins but no metallic minerals were noted except pyrite, which occurs in small disseminated specks in a gangue of quartz and calcite.

The Clarno basalt has been crushed and used locally as a road base, and sandstone from the Mitchell beds has been used locally as a building stone.

HISTORICAL GEOLOGY

The earliest event which the rocks record is the accumulation of marine sediments. These sediments, after compaction, were folded, intruded, metamorphosed, uplifted, and eventually eroded. These old rocks, the Tony Butte meta-sediments, contain marine fossils which suggest that they are Upper Paleozoic in age, perhaps Pennsylvanian or Permian. There is no further record in the area until Lower Cretaceous time and this large gap in the geologic column suggests either that no further deposition occurred or that the rocks which were deposited were completely eroded away before the encroachment of a Cretaceous sea.

The initial transgression of this sea was over the truncated edges of the old rocks and resulted in a basal deposit of sand and gravel, probably derived from adjacent areas which contained rocks similar to the meta-sediments now exposed in the area. A notable exception to the local derivation is the abundant meta-volcanic material in the sediments which indicates considerable pre-Cretaceous vulcanism and suggests that the source area may have been the site of a former eugeosyncline. This is conjecture, and the location or nature of the source is not known.

These deposits in Lower Cretaceous time marked the beginning of a long and apparently continuous record of marine sedimentation in a geosyncline which persisted until the final withdrawal of the sea in Upper Cretaceous time.

Following the accumulation of the basal sands and gravels, several thousand feet of mud, with interbedded sand lenses, was deposited. The apparently conformable nature of the contact between the basal sediments and the Frizzell shale unit seems to indicate that sedimentation was continuous or nearly so. The finer muds and sands reflect either a reduction in the level of the source area or a change in the depositional site. Perhaps the source area was eroded to a low-lying landmass which supplied fine- and medium-grained clastics, or possibly the shoreline moved landward from the area so as to result in finer sedimentation. In any event, the angular grains of the interbedded sandstone, its lack of sorting, the clay matrix, and the presence of considerable feldspar point to a relatively close source, and suggest rapid burial. Near the end of the Horsetown stage a change in sedimentation occurred that resulted in the deposition of coarser material.

This coarser material which is found at the top of the Frizzell shale unit reflects the beginning of renewed tectonic activity in the source area. Judged by the lithology of the measured section of the

Frizzell conglomerate unit, a major uplift of the source area occurred and resulted in the deposition of several thousand feet of mixed clastics of which the principal constituents were sand and gravel. Coarse clastics were dumped rapidly into the subsiding trough and the size of the particles varied greatly within short distances depending upon the configuration and distance of the source area.

After the deposition of at least 3000 feet of this material the sea withdrew from the area and did not return. Following the compaction of the Mitchell beds deformation occurred, and the rocks were folded into a broad northeasterly trending anticline which was uplifted and eroded, prior to the volcanic activity which inaugurated the Tertiary Period.

Initially, several hundred feet of andesitic pyroclastics and basalts were extruded. Some of the ash was reworked by streams and collected in low spots on the topography to form tuffs. Following this first widespread extrusion, a thick unit of porphyritic basalts of considerable petrographic diversity was poured out from numerous local volcanoes. Locally, andesitic tuffs were ejected and some dacitic flows occurred. During the late stages of this volcanic activity many basaltic, andesitic and dacitic masses were intruded in the form of plugs, dikes, and sill-like bodies which laced and disrupted the country rock. Simultaneously, strike faulting probably connected with the emplacement of the intrusives occurred on the northwest limb of the Mitchell anticline. Compressive forces again were directed from the northwest and southeast and the Clarno formation was folded. Presumably the structural trend which had been established at the close of the Cretaceous Period was followed, as it would be in successive epochs. The Eocene ended with the uplift and erosion of the Clarno volcanics.

In Middle and Upper Oligocene and Lower Miocene time tuffs of the John Day formation accumulated on the erosion surface of the Clarno formation. It has been suggested and verified by previous investigators that the lower beds are partially lacustrine in origin and that the Middle and Upper John Day beds are largely aeolian in origin. During the accumulation of the Middle John Day beds a "nuees ardentes" type of eruption occurred, and a layer of welded tuff was deposited. A period of erosion followed the accumulation of the John Day tuffs.

In Middle Miocene time the Columbia River basalt was extruded over the area. At least nine separate flows occurred in the vicinity of Sutton Mountain and it appears that much, if not all, of the area was blanketed by this lava. The Columbia River lavas are the last evidence of vulcanism in the mapped area. Further folding and erosion occurred afterward.

During the Quaternary, streams flowing from Sutton Mountain towards Bridge Creek developed a gently sloping surface upon the John Day tuffs. Alluvial fans were then deposited upon this surface. Bridge Creek and its tributaries then cut through these fans and once again exposed the John Day formation.

At a later date, alluvial gravels, sands, silts, and ash were deposited along Bridge Creek and Meyers Creek. Following this deposition the streams cut through these deposits and left remnants above the present stream levels.

At the present time erosion is the dominant process in the area.

SUMMARY AND CONCLUSIONS

Rocks ranging in age from Paleozoic to Recent are present within the mapped area, including the Tony Butte meta-sediments of probable Mississippian or Lower Pennsylvanian age; the Mitchell beds of Cretaceous age; the Clarno, John Day and Columbia River basalt formations of Tertiary age; and Quaternary deposits.

Both the meta-sediments and the Mitchell beds are thought to be marine deposits. The thickness and nature of the sediments comprising the Mitchell beds suggest that they were deposited in a geosyncline and the association of volcanic pebbles with other components of the conglomerates in the upper unit of the Mitchell beds indicates that the source area may have been the site of a former eugeosyncline.

The discovery of marine fossils in the Tony Butte meta-sediments and in the conglomerates in the upper parts of the Mitchell beds has substantiated the lithologic correlations of earlier workers.

The Clarno formation in this area is composed of andesitic breccias and mudflows near the base, a diversity of basaltic rocks in the main mass, and dacitic rocks near the top of the formation.

The lithologies of the John Day and Columbia River Basalt formations appear to be similar in most respects to those described by other workers in the Dayville and Picture Gorge quadrangles.

Intrusive rocks are common and consist of dacitic, andesitic, and basaltic types in the form of plugs, dikes, and sill-like bodies. The precise age of these rocks was not established but on the basis of their field relations within the area they tentatively are assigned an age of Late Eocene or post-Eocene, pre-Upper Oligocene. One exception is the olivine basalt intrusives which are believed to represent feeder dikes of the Columbia River Basalt formation. These are assigned to the Middle Miocene.

Structurally the area is characterized by the northeasterly trending Mitchell anticline which passes through the central part of the area. It plunges to the northeast in the vicinity of Tony Butte and the Mitchell beds which are exposed along the anticline plunge beneath Tertiary lavas in the vicinity of the Waldron School. Strike faulting and the emplacement of intrusive rocks have obscured and complicated the anticlinal nature of this fold.

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